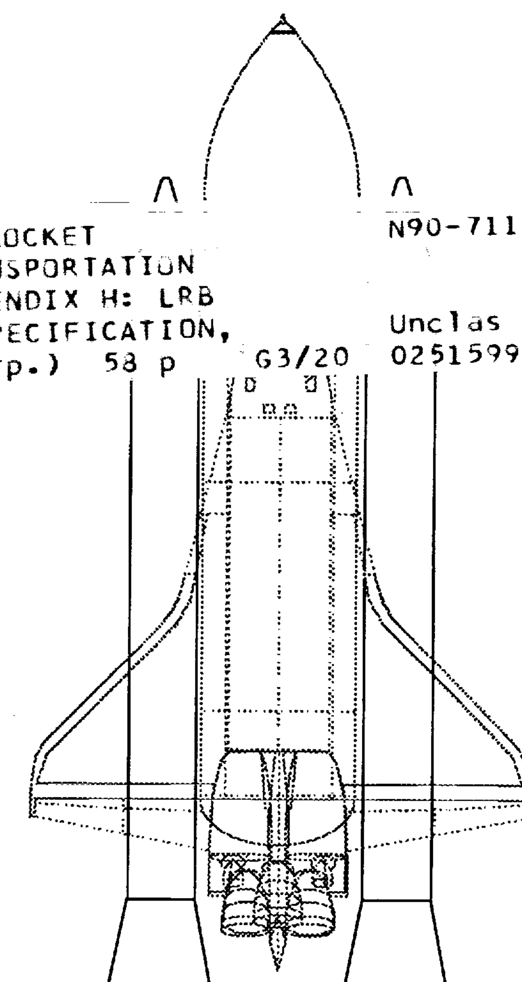
NAS8-37136

March 1989

Appendix H
LRB for the STS
Systems Study
CEI
Specification,
Revision 1 May
1988

Liquid Rocket Booster (LRB) for the Space Transportation System (STS) Systems Study



(NASA-CR-183794-App-H) LIQUID ROCKET BOOSTER (LRB) FOR THE SPACE TRANSPORTATION SYSTEM (STS) SYSTEMS STUDY. APPENDIX H: LRB FOR THE STS SYSTEMS STUDY CEI SPECIFICATION, REVISION 1 (Martin Marietta Corp.) 58 p

N90-71170

Unclas
G3/20 0251599

L-004/jer

MARTIN MARIETTA
MANNED SPACE SYSTEMS

LRB for the STS Systems Study
CEI Specification, Revision 1
May 1988

Appendix H

LIQUID ROCKET BOOSTER
(LRB)
FOR THE SPACE TRANSPORTATION SYSTEM (STS)
SYSTEMS STUDY

CEI SPECIFICATION
LRB DOCUMENT NO. - TBS
REVISION 1
MAY 1988

MARTIN MARIETTA
MANNED SPACE SYSTEMS

1.0 SCOPE

This specification establishes the requirements for performance and design of assemblies and mating hardware which shall be identified collectively as the Integrated Liquid Rocket Booster (ILRB) when mated to the launch structure and integrated into the Space Shuttle Flight System.

The order of precedence for this document shall be:

1. Space Shuttle Flight and Ground System specification, NSTS 07700, Volume X (Revised).

2. Level II Interface Control Documents - TBD

3. Contract end Item (CEI) Specification.

2.0 APPLICABLE DOCUMENTS

The following documents (all or in part) form a part of this specification.

SPECIFICATIONS

Military

MIL-B-5087 B Amended 2 31 August 1970	Bonding Electrical and Lightning Protection for Aerospace Systems
MIL-E-6051 D Amendment 1 5 July 1968	Electromagnetic Compatibility Requirements, System
MIL-H-5440 G November 28, 1975	Hydraulic Systems, Aircraft, Types I and II, Design and Installation Requirements for,
MIL-H-83282 A Int. Amendment 1 10 September 1976	Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft
MIL-H-8775 D June 11, 1976	Hydraulic Systems Components, Aircraft and Missiles, General Specification for
MIL-P-27401 C 20 January 1975	Propellant Pressurizing Agent Nitrogen
MIL-P-27407 A 28 November 1978	Propellant Pressurizing Agent, Helium
MIL-S-7742 B Amendment 1 15 March 1973	Screw Threads, Standard, Optimum Selected Series, General Specification for
MIL-S-8879 A Amendment 1 15 March 1973	Screw Threads, Controlled Radius Root with Increased Minor Diameter; General Specification for

National Aeronautics and Space Administration

JSC 07636 Revision C 1 August 1984	Lightning Protection Criteria Document
NSTS 07700 Volume X	Space Shuttle Flight and Ground System Specification
NSTS 07700 Volume IXX	Integrated Logistics Requirements Space Program Para. 3.2.4
JSC 08060 D January 28, 1983	Space Shuttle System Pyrotechnic Specification
MSFC-SPEC-101 B 15 March 1971	Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments which Support Combustion

SPECIFICATIONS (Continued)

MSFC-SPEC-106 B Amendment 1 6 October 1967	Testing Compatibility of Materials for Liquid Oxygen Systems
MSFC-SPEC-250 A 1 October 1977	Protective Finishes for Space Vehicle Structures and Associated Flight Equipment, General Specifications for
MSFC-SPEC-494 A April 30,. 1973	Installation of Harness Assembly, (electrical Wiring), Space Vehicle, General Specification for,
MSFC-SPEC-522 A 18 November 1977	Design Criteria for Controlling Stress Corrosion Cracking
SE-F-0044 A February 6, 1975	Filters, Wire Cloth, General Specification
SE-S-0073 C February 14, 1977	Fluid Procurement and Use Control, Space Shuttle
SL-E-0001 June 4, 1973	Electromagnetic Compatibility Requirements for the Space Shuttle Program
SL-E-0002 A 16 September 1974	Electromagnetic Interference Characteristics, Requirements for Equipment
SN-C-0005 March 6, 1974	Contamination Control Requirements for the Shuttle Program
SW-E-0002 B January 6, 1976	Ground Support Equipment, Space Shuttle General Design Requirements
16A03039 C June 20, 1984	Space Shuttle Range Safety System Signal Control, Specification for
30A90506 C June 17, 1983	Shuttle Range Safety System, Specification for,
40M35772 12 June 1972	Guideline for Incorporation of the Onboard Checkout and Monitoring Function on the Space Shuttle
40M39513 C 29 October 1981	Wire, Electrical, Hookup, General Specification for
40M39526 C 20 July 1983	Cable, Electrical, Shielded, Jacketed, Specification for

SPECIFICATIONS (Continued)

Contractor - Rockwell International

MC 450-0018 D July 12, 1979	Controller, Pyrotechnic Initiator,
MC 493-0015 D February 14, 1981	Gyro Assembly, Rate, Specification for,

STANDARDS

Military

MIL-STD-130 F 21 May 1982	Identification Marking of U.S. Military Property
MIL-STD-143 B November 12, 1969	Standards and Specifications, Order of Precedence for the Selection of
MIL-STD-280 A July 7, 1969	Item Levels, Item Exchangeability, Models and Related Terms, Definition of
MIL-STD-454 H June 30, 1982	Electronic Equipment, Standard, General Requirements for
MIL-STD-461 A Notices 1,2,5, & 6 3 July 1973	Electromagnetic Interference Characteristics, Requirements for Equipment
MIL-STD-462 Notices 1 and 2 1 May 1970	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-463 A June 1, 1977	Electromagnetic Interference and Electromagnetic Compatibility Technology, Definitions and System of Units
MIL-STD-810 D July 19, 1983	Environmental Test Methods,
MIL-STD-1247 B 20 December 1968	Markings, Functions, and Hazard Designations of Hose, Pipe, and Tube Lines for Aircraft Missile, and Space Systems
MIL-STD-1472 C May 2, 1981	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MIL-STD-1574 A August 15, 1979	System Safety Program for Space and Missile Systems

National Aeronautics and Space Administration

JSCM 8080 April 26, 1971	Manned Spacecraft Design Criteria and Standards
20M02540 14 May 1973	Assessment of Flexible Lines for Flow Induced Vibration

OTHER PUBLICATIONS

Data Books - Rockwell International/SD

SD73-SH-0069-2C Revision 5 August 1978	Space Shuttle Structural Design Loads Data Book
SD74-SH-0082A October 1977	Space Shuttle System Acoustics and Shock Data Book
SD74-SH-0144D Revision 4 22 January 1982	Space Shuttle Program Thermal Interfaces Design Data Book

Handbooks - Military

MIL-HDBK-5D June 1, 1983	Metallic Materials and Elements for Vehicle Structures
MIL-HDBK-17 A Part I - January 1971 Part II - June 8, 1977	Plastics for Aerospace Vehicles Part I - Reinforced Plastics Part II - Transparent Glazing Materials
MIL-HDBK-23A December 30, 1968	Structural Sandwich Composites,

Handbooks - National Aeronautics and Space Administration

MSFC-HDBBK-505 A January 1981	Structural Strength Program Requirements
NHB 5300.4 (ID-2) October 1979	Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program

Manuals - Military

ESMCR 127-1 30 July 1984	Range Safety Regulation Eastern Space and Missile Center
WSMCR 127-1 15 May 1985	Range Safety Regulation Western Space and Missile Center

Plans - National Aeronautics and Space Administration

NSTS 07700-10-MVP	Shuttle Master Verification Plan General Approach and Guidelines
10A00562 11 May 1978	Electromagnetic Effects Control Plan Range Safety Program

OTHER PUBLICATIONS

Other Documents - National Aeronautics and Space Administration

NSTS 07700 Volume VII	Commonality Management, Space Shuttle
JSC 09084 October 1974	Coordinate System for the space Shuttle Program
SE-019-043-2H May 20, 1975	Natural Environments for the Space Shuttle Solid Rocket Booster
20M02540 B November 2, 1979	Assessment of Flexible Lines for Flow Induced Vibration
TM 82473 1982	Terrestrial Environment (Climatic) Guidelines for Use in Aerospace Vehicle Development, 1982 Revision

3.0 REQUIREMENTS

3.1 CEI Definition, Integrated Liquid Rocket Booster

3.1.1 General Description. The ILRB shall consist of one left-hand and one right-hand assembly stacked in parallel and attached to the launch structure and to an External Tank (ET) with the mating hardware. These stacked assemblies are referenced herein as Liquid Rocket Boosters (LRBs) for convenience, with all paragraphs applicable to an LRB applying equally to both the left-hand and the right-hand LRB unless otherwise stated. Each LRB shall consist of an engine subsystem, a structural subsystem, a separation subsystem, an electrical instrumentation (E&I) subsystem, a Thrust Vector Control (TVC) subsystem, a recovery subsystem, and a Range Safety (RS) subsystem. The mating hardware shall attach the LRBs to the launch structure and to the ET and shall have the capability to destruct in releasing the ILRB from the launch structure and in separating the LRBs from the ET.

3.1.2 Operational Concepts. The space shuttle flight system when configured for launch, shall consist of an Orbiter Vehicle (OV) and an ILRB attached to and in parallel with an ET. The LRBs of the ILRB shall be attached to opposite sides of the ET. The OV shall contain three Space Shuttle Main Engines (SSMEs) fueled by cryogenic propellants supplied by the ET.

The boost phase of the flight system shall be accomplished by operating the LRB's in parallel with the SSMEs for added impulse and thrust vector control from lift-off to ILRB separation.

3.2 Characteristics

3.2.1 Performance

3.2.1.1 General Performance

3.2.1.1.1 Ascent Control. The TVC on each LRB, in conjunction with the TVC on the SSME shall provide ascent control authority in roll, pitch, and yaw.

3.2.1.1.1.1 ILRB/ET Attachment Loads. The ILRB/ET attachment structures and mechanisms shall be capable of withstanding the loads specified in 3.2.7.2.

3.2.1.1.2 Separation Phase. The separation subsystem of each LRB shall include: (a) the capability to accept and respond to separation commands orginating in the Orbiter based on dedicated separation and control requirements and cues for separation, (b) a release function, and (c) BSMs to translate the LRB away from the Orbiter/ET. All sequencing and commands shall come from the Orbiter. The release hardware and BSMs shall be the responsibility of the LRB.

3.2.1.1.3 Recovery Phase.

3.2.1.1.3.1 LRB Descent. (TBD)

3.2.1.1.3.2 LRB Flotation. (TBD)

3.2.1.1.3.3 LRB Retrieval. (TBD)

3.2.1.1.3.4 LRB Safing. The LRB shall be capable of being safed prior to initiation of retrieval operations.

3.2.1.1.4 Loading Conditions. The ILRB structures shall be capable of meeting the loading conditions specified in the following subsections.

3.2.1.1.4.1 Prelaunch. For the purposes of this document, the prelaunch period extends from final assembly of the LRBs until LRB ignition. The ILRB assembled with the Orbiter and External Tank shall have free standing capability on the Mobile Launcher Platform (MLP) at Kennedy Space Center (KSC) or the Launcher Platform (LP) at Vandenberg Air Force Base (VAFB) under the following conditions:

a. Withstanding ground winds as specified in SE-019-043-2H.

b. Withstanding the combined loads of wind, propellant loading, vehicle body and launch pad/MLP at KSC or Launch Pad/Platform at VAFB flexibilities, and the effects of vortex shedding and other unsteady flow phenomena as specified in 3.2.7.1 and 3.2.7.2.

3.2.1.1.4.2 Launch. For the purposes of this document, the launch period extends from the initiation of ILRB ignition until all structural response transients (following vehicle release) have dampened out. The ILRB shall be capable of being launched under the following conditions:

a. Environment - Withstanding ground winds, acoustic sound levels, vibration levels, and thermal conditions as specified in SE-019-043-2h and 3.2.7.2.

b. Engine Start Transients - The ILRB shall be capable of withstanding ILRB and Orbiter induced start transient and misalignment loads as specified in 3.2.7.2.

c. Launch Release - the ILRB shall be capable of withstanding the loads due to vehicle release including dynamics effects associated with the transverse shear and bending moment induces by the wind profile, thrust misalignments, and thrust buildup transients. Release loads shall be as specified in 3.2.7.2.

d. Acceleration at Lift-off - The ILRB shall be capable of withstanding the rigid body and elastic body accelerations at lift-off as specified in 3.2.7.2.

3.2.1.1.4.3 Ascent. For the purpose of this document, the ascent period extends from the completion of launch until ILRB separation. The ILRB shall be capable of ascent flight under the following conditions:

a. Environment - The ILRB shall be capable of withstanding the natural environment of flight winds, wind shears and gusts, and the induced environment of acoustic sound pressure levels, vibrations, shocks as specified in SE-019-043-2H, 3.2.7.1 and 3.2.7.2.

b. Aerodynamic Effects - The ILRB shall be capable of withstanding aerodynamic heating and dynamic pressure effects as specified in 3.2.7.2.

c. Engine Thrust Transients - (TBD)

d. Dynamic Loads - The ILRB structure shall be capable of withstanding the loads presented in 3.2.7.2.

3.2.1.1.4.4 Reentry. (Deleted)

3.2.1.1.4.5 Recovery. (Deleted)

3.2.1.1.4.5.1 LRB. (Deleted)

3.2.1.1.4.5.2 Frustum. (Deleted)

3.2.1.1.4.6 Retrieval. (Deleted)

3.2.1.1.4.6.1 LRB. (Deleted)

3.2.1.1.4.6.2 Frustum. (Deleted)

3.2.1.1.5 Shuttle Flight Vehicle Checkout. The ILRB shall be capable of launch readiness checkout with support from the Orbiter after ground system connection on the launch pad.

3.2.1.1.5.1 Checkout. The LRB electrical subsystem shall incorporate the capability for the following checkout provisions:

a. Provide capability in LRB to utilize ground power for all tests and ground operations.

b. Maximum use of flight functions for checkout.

c. End-to-end check where feasible; where not feasible, maximum circuit checkout provisions for injecting stimuli/simulation at nearest feasible point to item being checked.

d. Interface integrity verification by end-to-end checks and visual inspection of mated connectors.

e. End-to-end LRB functional verification in a mated vehicle configuration without drag-on simulation/stimulation.

f. Fault-isolate to the Line Replaceable Unit (LRU) (or group of LRU) Level without disconnections or use of carry-on equipment.

g. Redundancy verification in place.

3.2.1.1.5.2 Preparation and Servicing. The LRB shall have the capability to meet the following requirements.

a. Mechanical buildup and LRB premate inspection within a period of (TBD) hours.

b. The installation of ship loose LRB/ET interface equipment within a period of two (2) hours.

c. Support launch readiness checkout, as required after vehicle assembly, within a period of four (4) hours.

d. The Range Safety System (RSS) shall have launch site installation capability for installation of the safe and arm device, Linear shaped Charges (LSC), Apollo standard detonating cartridges, the RSS LRB/ET interface brackets, CDF assemblies not installed in cable trays, and GFP avionics.

e. Routine ground service operations shall not be required after roll out, unless resulting from requirements of ICD's imposed (TBD).

f. The LRB shall be capable in conjunction with the ET of alignment, connection, inspection, and verification of electrical and mechanical interfaces during the mating operations.

3.2.1.1.6 ILRB/MLP Mating. The ILRB/MLP at KSC or the ILRB/Platform at VAFB mating shall be in accordance with (TBD).

3.2.1.1.7 ILRB/ET Buildup and Mating. The LRB shall be capable of servicing, verification and assembly on the MLP at KSC or on the LP at VAFB prior to ET mating. The ILRB shall be capable of alignment, connection, and verification of mechanical and electrical interfaces during mating operations. ILRB/ET assemblies shall meet the alignment criteria of (TBD).

3.2.1.1.8 Loading and Draining. The LRB shall be capable of simultaneous and/or sequential LO2 and RP-1 loading and/or draining. The LRB shall have a minimum hold capability, after propellant loading, of seven (7) hours including two (2) minutes pressurized to flight pressurization levels down to T-35 seconds. The design shall not preclude main propellant drain and subsequent reload with no manual operation on the launch pad.

3.2.1.1.9 LRB Debris Footprint. Maximum footprint of tank debris due to ballistic coefficients and atmosphere, shall be a footprint of (TBD) n. mi. along track and (TBD) n. mi. crosstrack. The footprint specified does not include the effects trajectory dispersions or premature operation of the Range Safety System.

3.2.1.1.10 Post Separation Venting. Post Separation Venting of the LRB for a period of 60 seconds after separation from the ET shall not cause recontact of the LRB with the ET or the Orbiter.

3.2.1.1.11 LO2 Slosh Damping. The LRB shall provide slosh damping in the LO2 tank. The slosh damping requirements for nominal mission conditions shall be as defined in Table 3.2.1.1.11.

DAMPING (1)	CONDITION (2)	WAVEHEIGHT (3)	FLUID LEVEL (4)	MASS/TIME FUNCTION (5)
0.2	Ms/Mv 0.1	(TBD)	(TBD)	(TBD
0.5	All	(TBD)	(TBD)	(TBD)
1.0	All	(TBD)	(TBD)	(TBD)

TABLE 3.2.1.1.11 LRB LOX SLOSH DAMPING

NOTES:
(1) Percentage of Critical Damping minimum
(2) Flight Condition, Ms/Mv is the ratio of first slosh mass to total vehicle mass
(3) Zero-to-peak waveheight at tank wall, in inches
(4) Fluid Level, inches from tank bottom
(5) Slosh mass-vs-time function shall be based on nominal mission conditions

3.2.1.2 Propulsion and Mechanical Subsystem Performance

3.2.1.2.1 General. The propulsion and mechanical subsystem shall provide oxidizer and fuel to the LRB engine interface. It shall include provisions for propellant management and control, pressurization, and venting. Inerting purge shall be provided during ground operation.

3.2.1.2.2 Performance Requirements

3.2.1.2.2.1 LO2 and Fuel Fill, Feed, and Drain. Separate LO2 and Fuel lines shall control the transfer of propellants between the tanks and the LRB engine interface. The LRB shall filter propellants at the fuel and LO2 tank outlets. The filters shall prevent spherical particles greater than 800 microns from passing from the main propellant tanks into the propellant feed system. The propellant filters shall meet the requirements of SE-F-0044.

3.2.1.2.2.1.1 POGO Suppressor Requirements. A POGO suppressor shall be provided on each LRB engine, if needed. The effective point of application of the suppressor for LRB engines is (TBD).

3.2.1.2.2.1.1.1 Compliance (TBD).

3.2.1.2.2.1.1.2 Inertance (TBD)

3.2.1.2.2.1.1.3 Helium and Electrical Power Consumption. The suppressor design and operations shall minimize helium and electrical power consumption which will be supplied by the LRB.

3.2.1.2.2.1.2 Propellant Utilization. A system of propellant utilization shall be provided for the LRB. The system shall be either an interactive system to control engine mixture ratio or a system utilizing fuel loading bias and level/depletion sensors. Further requirements are (TBD).

3.2.1.2.2.2 Antigeysering. Geysering in the LO2 system shall be prevented during all phases of propellant loading, pre-launch, replenish, and detanking. This includes any revert during propellant loading. A continuous flow of helium shall be supplied by the launch facility.

3.2.1.2.2.3 LO2 and Fuel Tank Pressurization. The LRB shall accommodate LO2 and fuel tank prepressurization by ground supplied gas. The LRB shall accommodate or onboard pressurant flow which shall be supplied and controlled by the LRB.

3.2.1.2.2.4 GO2 and Fuel Vent and Relief. LRB design shall include a system for ground venting during all phases of propellant loading. The GO2 system and the fuel system shall vent thru GSE/LRB vent ducts. The system shall be designed to satisfy loading timelines specified (TBD), loading flow conditions specified in (TBD), and to satisfy propellant conditions required (TBD). In-flight relief and ground relief shall also be provided to maintain tank pressures at a level of no greater than 3 psig above maximum operating pressure.

3.2.1.2.2.5 Propellant Tank Purge. The LO2 and fuel tanks shall be capable of being purged with helium, nitrogen, or air. Flow will enter the LO2 and fuel tanks via the fill, feed, and drain lines and/or the pressurization lines. Flow will exit the LO2 and fuel tank via the fill, feed, and drain lines and/or the vent lines.

3.2.1.2.2.5.1 Nose Cavity Conditioning. The Nose Cavity shall be capable of being conditioned with gaseous nitrogen during ground operations as required for environmental control for components.

3.2.1.2.2.5.2 Electrical Umbilical Purge. The electrical umbilicals shall be capable of being purged with LRB supplied purge gas.

3.2.1.2.2.6 Intertank Purge. The intertank area shall be capable of being purged directly from the ground with GN2, prior to, during, and subsequent to cryogenic tanking for safety. The flow rate shall keep the hazardous gas content below the 4% concentration level. The purge gas shall be heated, by facility in accordance with ICD (TBD), to prevent ice/frost formation at the intertank vent and leak areas. The intertank shall also be capable of accepting a breathable air purge for ground personnel entry.

3.2.1.2.2.7 Propellant Loading. The LO2 and fuel tanks shall provide for a 100% Mass Quantity Loading such that the maximum errors are (TBD)% and (TBD)%, respectively. The LRB propellant loading system shall have the capability to support a vehicle launch from a standby status within 120 minutes. Vehicle access shall be permitted for not less than 45 minutes of consecutive times within the 120 minutes to accommodate flight crew ingress and final prelaunch closeout. The LRB shall be capable of being loaded with cryogenic propellants in 75 minutes from start of propellant transfer system-chill down to 98% full. The design shall provide for main propellant drain and subsequent reload with no manual operation on the pad.

3.2.1.2.2.8 Propellant Level Sensing. The LO2 and fuel tanks shall include a level sensing system capable of preassembly adjustment to permit level sensing between the 99% and 100% LRB mass quantity loading when the LRB is in the vertical position.

3.2.1.2.2.9 Propellant Depletion. The Propellant Depletion sensors in the LO2 Feedline and in the fuel tank shall provide four (4) LO2 depletion signals and four (4) fuel depletion signals to the LRB for LRB engine cutoff.

3.2.1.2.2.10 Lines. All lines shall be designed to accept loads resulting from misalignments due to tolerance buildup and structural and thermal deflections. Flexible duct bellow system shall be designed to eliminate or minimize flow induced vibration. All LRB flexible line designs shall be assessed for flow induced vibration per MSFC standard 20M02540. Lines shall be sized for flow velocities to preclude flow induced vibration.

3.2.1.2.11 Hazardous Gas detection (HGD). The LRB shall provide a HGD manifold system to be used in conjunction with a mass spectrometer based analyzing system for sampling the intertank atmosphere at points six (6) to twelve inches from each of the intertank ports and at the LO2 feedline penetration. The HGD shall interface with the ground system at the intertank umbilical carrier plate.

3.2.1.2.12 Tank/Liquid/Flight Control Coupling. Tanks containing liquid shall be designed to prevent or suppress coupling between slosh of the liquid vehicle structure and the STS flight control system. Any modifications to the current STS flight control to effect acceptable vehicle stability shall be minimized by appropriate tank design solutions.

3.2.1.3 LRB Structural Subsystem. (TBD)

3.2.1.3.1 Nose Assembly. (TBD)

3.2.1.3.2 Mechanical Attachments. (TBD)

3.2.1.4 LRB Separation Subsystem. Separation of the LRBs from the Orbiter/ET shall occur only after ILRB shutdown. The separation subsystem shall include: (a) the capability to accept and respond to separation commands originating in the Orbiter, (b) A release system, and (c) BSM system to translate the LRBs away from the Orbiter/ET. All sequencing and commands shall come from the Orbiter. The release hardware and BSMs shall be the responsibility of the LRB. Hardware commands from the Orbiter to the LRB IEAs shall initiate the separation sequence.

3.2.1.4.1 Release System. The release system shall be compatible with the separation sequence specified in 3.2.1.3.3. Any component disconnect or breakwire at release shall not induce an impulse torque in excess of 700 ft-lb-sec about the LRB center of gravity at separation.

3.2.1.4.2 BSM Cluster. Separation motors shall be installed in a forward LRB position and in an aft position. At both the forward and aft locations there shall be a cluster of (TBD) BSMs. At both locations, the thrust vector of the BSM cluster shall be parallel $\pm$ 4 degrees to a plane containing the LRB centerline which is rotated 20 degrees about the centerline from the LRB + Z axis toward the ET (Figure 2). The thrust vector of the forward cluster shall pass within 2.6 inches of the LRB centerline. The thrust vector of the aft cluster shall be offset 1.95 $\pm$ 3.9 inches from the LRB centerline toward the ET in a direction normal to the 20 degree plane. In addition, the thrust vector of each cluster shall be pitched, in the 20 degree plane, 40 $\pm$ 4 degrees from the LRB Y-Z plane; the forward cluster shall be pitched forward and aft cluster shall be pitched aft. The BSMs shall be designed to operate over a propellant bulk temperature range of 30 to 120 degrees F. Each cluster of (TBD) motors shall provide the following vacuum performance over the entire propellant operating temperature range:

a. Average thrust over the web action time not less than TBD lbs.

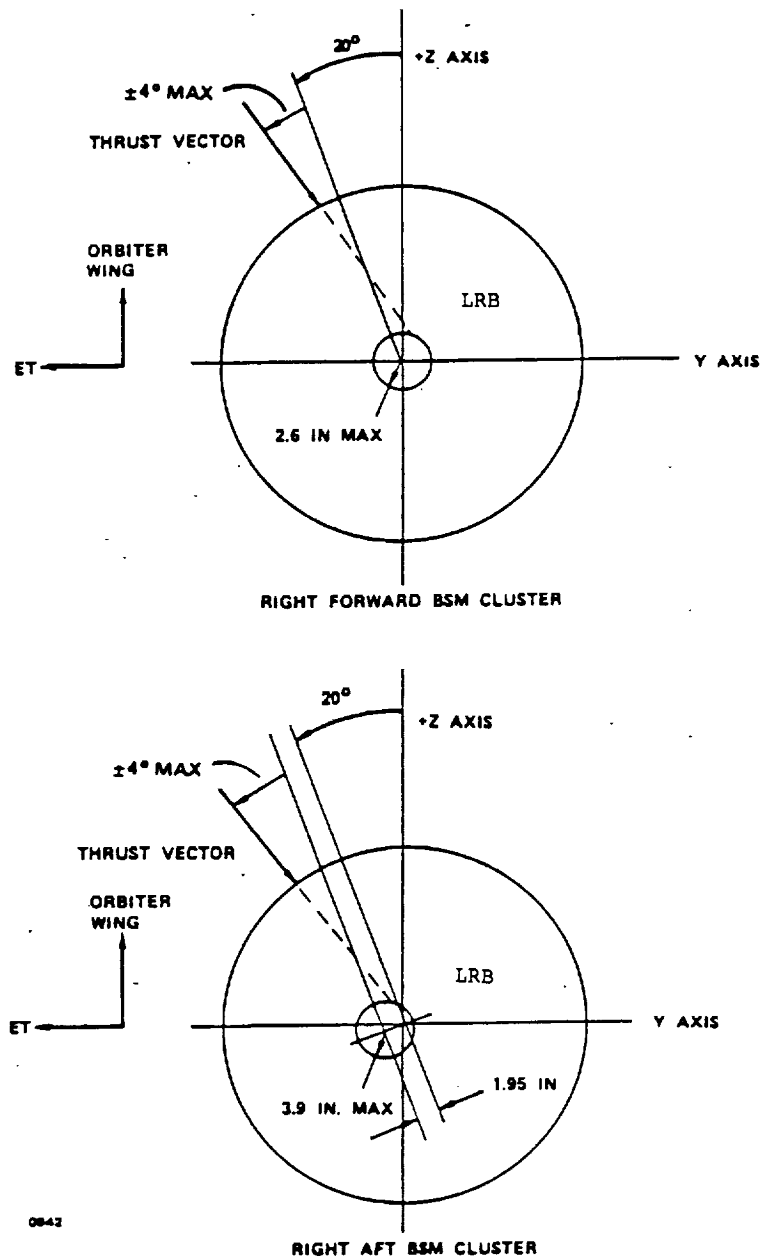


FIGURE 2 RIGHT BSM CLUSTER THRUST VECTOR ORIENTATION TOLERANCES
(NOTE: LEFT BSM CLUSTER THRUST VECTOR ORIENTATION TOLERANCE DIAGRAMS ARE A MIRROR IMAGE OF THE DIAGRAMS SHOWN.)

b. Neutral or regressive chamber pressure trace.

c. Total impulse over the web action time not less than TBD lb-sec.

d. Total impulse over the action time not less than TBD lb-sec.

e. Thrust rise characteristics shall be compatible with sequencing requirements specified in 3.2.1.3.3.

f. The time from BSM ignition start until the chamber pressure during thrust tail-off is one-half the chamber pressure at end of web action time (PEWAT/2) shall not exceed 1050 milliseconds for each BSM.

g. Web action time not greater than 0.805 seconds.

3.2.1.4.3 ILRB Separation Sequence. Initiation and control of the ILRB separation sequence shall be by Orbiter command. Each LRB shall furnish redundant (TBD) signals to the Orbiter. The separation sequence shall be initiated by the Orbiter when the indicated (TBD) on both LRBs is less than or equal to (TBD). The backup separation cue shall be mission elapsed time.

The Orbiter command to the nozzle of each LRB shall be issued at a time from sequence initiation which assures that all nozzles are in position for separation. The nozzle position is 0.0 ± 1.0 degree from the LRB centerline in the vehicle pitch axis and 1.0 ± 0.6 degree from the LRB centerline, toward the ET, in the vehicle yaw axis. This position shall be maintained for at least 5 seconds after separation command issuance.

The separation subsystem of each LRB shall provide for concurrent initiation of structural release and BSM ignition of both LRBs. Release of all structural attachments shall occur within 30 milliseconds and the thrust (vacuum) of each cluster of four BSMs shall reach TBD pounds within 30 to 135 milliseconds of the time at which the separation command crosses the Orbiter/LRB interface.

3.2.1.4.3.1 Debris. The BSMs shall not release any debris which could damage the Orbiter Thermal Protection System (TPS) during separation under design conditions. The Separation Subsystem shall not release any debris which could cause damage to any Orbiter/ET system or subsystem during separation under design conditions. The BSMs thermal environment to the Orbiter/ET is specified in 3.2.7.2.

The above requirement is waived for the following specific LRB items, materials, and locations where potential debris generation may occur to allow the LRB design to produce small amounts of debris during ascent and during LRB/ET separation.

The sources of this debris are as follows: (TBD)

3.2.1.4.4 ILRB Abort Separation. (TBD)

3.2.1.5 LRB Recovery Subsystem. (Deleted)

3.2.1.5.1 Nose Cap. (Deleted)

3.2.1.5.2 Drogue Parachute. (Deleted)

3.2.1.5.3 Main Parachutes. (Deleted)

3.2.1.5.4 Flotation Equipment. (Deleted)

3.2.1.5.5 Location Aids. (Deleted)

3.2.1.5.6 Design Factors. (Deleted)

3.2.1.5.7 Temperature Constraints. (Deleted)

3.2.1.5.8 Towing Pendant. (Deleted)

3.2.1.5.9 Recovery Subsystem Reliability. (Deleted)

3.2.1.6 LRB E&I Subsystem. The E&I subsystem shall consist of electrical components, instrumentation, and associated wiring.

3.2.1.6.1 Uses. (Deleted)

3.2.1.6.2 Simplex, Duel, Triplex, and Quadruplex Functions. (TBD)

3.2.1.6.3 Component Locations. (TBD)

3.2.1.6.4 Ordnance Control. All ordnance circuits in the electrical system shall utilize Pyro Initiator Controller (PICs) per specification MC450-0018 and shall meet the requirement of JSC-08060, and ESMCRM 127-1 at KSC or WSMCR 127-1 at VAFB.

3.2.1.6.5 Control Sensors. (Deleted)

3.2.1.6.6 Recovery Phase Functions. (Deleted)

3.2.1.6.7 Operational Measurements and Commands

3.2.1.6.7.1 Measurements. (TBD)

3.2.1.6.7.2 Sensors. Instrumentation sensors shall be provided for pressure, temperature, propellant level, and position measurements.

3.2.1.6.7.2.1 Sensor Accuracy. Temperature sensors shall conform to a standard platinum resistance characteristics curve of not greater than ± 1.5% of full scale.

3.2.1.6.7.2.2. Sensor Location. Instrumentation sensors shall be located in accordance with the instrumentation Program and Component List.

3.2.1.6.7.3 Commands. All critical commands shall be provided to the LRB via hardware with the exception of (1) RGA A&B power on, (2) S&A Arm, and (3) TVC Auxiliary Power Unit (APU) start command and lock on which is provided by the Multiplexer/Demultiplexer (MDM). Noncritical commands shall be multiplexed from the Orbiter to the LRB. The E&I subsystem shall provide capability to demultiplex digital commands.

3.2.1.6.8 Electrical. The E&I subsystem shall include all cables used to distribute electrical signals within the LRB and to and from the LRB/Orbiter interface, and furnish the power, control and distribution of electrical signals for all other LRB subsystems.

3.2.1.6.8.1 Power. Electrical power of nominal 28 volts dc for LRB operational equipment shall be provided from redundant batteries - TBD (see 3.2.1.6.9.5). Loss of one redundant bus shall not cause any loss of any E&I ascent system function.

3.2.1.6.8.2 Power Distribution. The E&I subsystem shall control and distribute LRB bus power to the operational systems.

3.2.1.6.8.3 RS-B Battery Power. RS-B Battery power shall be used for the following function:

a. Dedicated power for the RS subsystem B during LRB powered flight.

3.2.1.6.8.4 Electrical Support Equipment (ESE) Power. During ground test the E&I subsystem shall distribute ground power to the E&I elements.

3.2.1.6.8.5 Power Characteristics.

a. Two-wire system shall be used; i.e., power return lines are not to be grounded to structure within the LRB.

b. LRB Steady State Voltage.

(1) Normal Operation - Steady state limits shall be 26.15 vdc to 32 vdc for Buses A and B and 25.6 vdc to 32 vdc for Bus C.
(2) One Bus Failed Operation - Steady state limits shall be 25.7 vdc to 32 vdc for buses A and B and 25.2 vdc to 32 vdc for Bus C.

c. LRB Voltage Transient Limits.

(1) Prior to T-1 minute the limits shall be 26.15 vdc to 36.7 vdc with recovery to steady state limits within 200 milliseconds.

(2) From T-1 minute through ascent and separation, bus loads switching transients shall be 1.8 volts (1 vdc and .8 v ripple) below the specified interface voltage with recovery to steady state within 200 milliseconds.

(3) Power Bus Switching Transient: The Orbiter shall provide the capability for switching to back-up power buses when the interface voltage falls below 22.0 volts for 40 $\pm$ 10 milliseconds with recovery to steady state within 100 milliseconds.

d. Maximum open circuit voltage of the silver-zinc RS-B battery shall not exceed 35.5 VDC. The open circuit voltage shall decay to 32.0 VDC within 200 milliseconds after a load of 250 milliamps or more is applied.

3.2.1.6.9 Location Aids. (Deleted)

3.2.1.6.10 Development Flight Instrumentation (DFI). A DFI subsystem shall be provided as required to support design changes or investigate flight operating conditions.

3.2.1.7 LRB TVC Subsystem. The TVC subsystem shall provide pitch, roll, and yaw vehicle movements upon receipt of command signals from the Orbiter and shall comply with the requirements of this specification.

3.2.1.7.1 Configuration. The TVC subsystem for each LRB shall consist of two electric power supplies, electro-mechanical actuators, control unit, and various wiring, and brackets.

3.2.1.7.1.1 General Requirements. (TBD)

3.2.1.7.1.2 Electro-Mechanical. (TBD)

3.2.1.7.1.3 Electric Power Supplies. Each electric power supply shall consist of (TBD batteries) and required distribution system. The electric power supplies shall:

a. Be capable of driving their primary (tilt or rock) actuator at rated load.

b. Be so interconnected that if either power supply fails, the remaining power supply shall be capable of driving all actuators at a reduced rate.

c. Be capable of supporting both horizontal and vertical LRB firings.

3.2.1.8 Ground Equipment. (TBD)

3.2.1.8.1 General Requirements for Support Equipment (SE), Special Test Equipment (STE), and Transportation Support Equipment (TSE). (TBD)

3.2.1.8.1.1 Modularity. Equipment should be of a modular design to provide flexibility for support of all levels of test and operations from bench test of vendor supplied assemblies to test of the complete booster, as well as refurbishment verification testing during turnaround activities.

3.2.1.8.1.2 Grounding/Shielding. Grounding of electrical/electronic circuitry shall be accomplished in a controlled manner so as to provide adequate voltage references compatible with LRB/facility grounding while preventing ground current from interfacing with circuits. Shielding of electrical/electronic circuitry shall be provided to electrically ground the LRB elements during transportation to prevent the buildup of static charge.

3.2.1.8.1.4. Reliability. Equipment reliability shall be determined by level of criticality of the function on a unit-by-unit analysis.

3.2.1.8.1.5 Safety. Equipment design shall not degrade the inherent safety of the equipment under tests. A failure in the equipment shall not injure or create a hazardous condition to personnel, propagate a failure sequentially in associated equipment to damage or degrade the flight vehicle. Equipment shall be designed to include the following safety considerations as a minimum:

a. Maintain operating and overrun temperature below ignition temperature of associated hazardous materials.

b. Hermetically seal, explosion proof, or purge all electrically active items during fueling operations.

c. Provisions for adequate relief valve(s) on equipment and purged enclosures.

d. Loads imposed on the LRB and/or system elements shall not exceed flight loads.

e All purge, desiccant, pressurization, etc., equipment required to maintain the LRB during transport operations shall contain adequate relief valve(s).

f. Provisions to prevent gas, fluid, or material ignition at umbilical connector and coupling interfaces.

g. Venting of hazardous or toxic gases into a collection system for safe disposal

h. Proper identification, marking, and control of sequences to prevent reversal of mismatching of fittings, coupling, electrical connectors, etc.

i. Filtering and contamination control shall be compatible with the flight systems.

j. Provide electrical/electronic equipment with adequate fusing and/or current limiting devices to minimize fire hazards and hardware damage to either ground or flight systems.

3.2.1.8.1.6 Software. Ground software programs for checkout (if required) shall be developed, verified, and provided along with associated equipment to effect a complete, homogeneous ground checkout capability. The software and test procedures will be developed to achieve a maximum amount of commonality at the various sites.

3.2.1.8.1.7 Transportation. Transportation equipment shall be designed such that the shock and vibration loads specified in 3.2.8 do not impact the design of light hardware. For new designs, refer to MSFC-HDBK-505.

3.2.1.8.2 GSE Fail-Safe. All GSE (except primary structure and pressure vessels) shall be designed to sustain a failure without causing loss of vehicle systems or loss of personnal capability (fail-safe).

3.2.1.9 LRB Ordnance System

3.2.1.9.1 LRB Ordnance Requirements.

3.2.1.9.1.1 LRB/ET Separation. The forward attach fitting and the three aft attach struts shall contain ordnance-actuated separation bolts that are failed in tension on initiation of ordnance pressure cartridges.

3.2.1.9.1.2 Separation Motor Ignition. Forward and aft separation motor ignition shall be provided by Confined Detonating Fuse (CDF) initiators activated by NSI-1 detonators through a CDF manifold and CDF assemblies.

3.2.1.9.1.3 Nose Cap Separation. (Deleted)

3.2.1.9.1.4 Reefing Line Cutter. (Deleted)

3.2.1.9.1.5 Frustum Separation. (Deleted)

3.2.1.9.1.6 Main Parachute Release. (Deleted)

3.2.1.9.1.7 RS LRB Destruct. (TBD)

3.2.1.10 Range Safety System (RSS). RSS shall be provided in accordance with 30A90506. RS subsystems shall be located in each LRB and in the ET. Subsystem design shall be in accordance with NSTS 07700, Volume X. Maximum use shall be made of component commonality for use in LRB and ET subsystems.

3.2.1.9.10.1 LRB Subsystems. Each LRB shall contain two completely redundant RS subsystems herein designated as A and B. The four subsystems shall be so cross-strapped to each other and to the ET subsystem that arm and fire commands processed by any of the LRB subsystems shall initiate destruct of the LRBs and the ET.

3.2.1.9.10.1 Power. The redundant LRB subsystems in each LRB shall operate from separate and isolated power sources. A dedicated silver zinc battery in each LRB shall provide power for RS subsystem A. The LRB alternate RS battery shall be dedicated to RS subsystem B during powered flight.

3.2.1.10.1.1.1. Power Distribution. The RS distributor shall control, by ground command, the application and distribution of RS power. Two redundant and isolated battery sources for RS A and B subsystems shall be separately controlled. RS subsystem power shall not have a power down capability from liftoff through cutoff of LRB thrust.

3.2.1.10.1.1.2 Power Characteristics. The silver zinc RS subsystem A battery open circuit voltage shall not exceed 30-36 volts dc. Battery voltage under load shall be 28 + 2, -1 volts. Power characteristics of the silver zinc battery shall conform to the requirements of 10SPC-0189. For the RS subsystem B battery power characteristics, refer to 3.2.1.6.8.5.

3.2.1.10.1.2 Pyrotechnics. Pyrotechnic components for the RS subsystem shall meet the requirements of JSC-08060.

3.2.1.10.1.3 Destruct system. RS subsystems shall include ground-commanded systems to destruct the LRBs. System components shall be reusable where cost savings will result.

3.2.1.10.1.3.1 RS Integrated Receiver Decoder (IRD). The IRD shall be operational RS flight hardware for subsystem A and B in each LRB, and for the simplex receiver-decoder subsystem in the ET. The IRD and necessary documentation shall be GFP.

3.2.1.10.1.3.2 Automatic IRD RS Test Set. An automatic RS test set shall be provided for checking IRDs. Test sets and necessary documentation shall be GFP.

3.2.1.11 Rate Gyro Assembly (RGA). Each LRB shall be provided with three RGAs which shall be installed in the forward area. The RGAs shall be in accordance with Specification MC493-0015 and (TBD).

3.2.1.12 Thermal Protection Subsystem Performance.

3.2.1.12.1 General. The LRB shall have a Thermal Protection Subsystem (TPS) based on SOFI characteristics which shall be sized to meet the specified propellant delivery requirements and to prevent ice accumulation in the LRB critical zone. The contractor shall utilize SOFI and/or pour foam as the TPS material for all LRB surfaces except that ablator and/or high propulsion line supports and closeouts, and localized hot spots. The TPS shall be applied as required to protect the LRB from aerodynamic and interference heating and engine exhaust heating. The TPS design shall be capable of repair prior to roll out to the launch site. The repair shall cure to sufficient strength, under local ambient conditions, to continue all activities (prior to roll out to the launch site) within 60 minutes after application. A thickness of one (1) inch $\pm$ 1/4 inch of SOFI/pour foam shall be applied to all LRB exterior cryogenic surfaces. The specified thickness shall be reduced in local areas, to permit implementation of feedthroughs, supports, flexible lines, and similar structure. Degradation of SOFI protuberances from flight environments shall not adversely affect LRB function. The TPS design shall minimize absorption and entrapment of liquids or gases which would degrade thermal or physical performance or present a fire hazard (wicking) and shall not require draining, drying, or any dedicated purge system from TPS closeout through launch.

3.2.2 Physical.

3.2.2.1 Mass Properties. (TBD)

3.2.2.1.1 Center of Gravity. (TBD)

3.2.1.1.1.1 LRB Center of Gravity. (TBD)

3.2.2.1.1.2 LRB Control Weight. (TBD)

3.2.2.2 Mass Properties (MP) Measurements. All LRB assemblies, excluding refurbished assemblies, shall be weighed to verify the analytical MP model and to minimize the expected MP dispersions of nominal predicted MP data.

Measurements shall be of major assemblies, maximum complete (at least 90 percent of weight), with minimum tare (less than 30 percent of weight). The weight accuracy requirement for each measurement is 0.2 percent for the reduced MP.

Measurement results shall be documented within 30 days and shall include MP accounting of the assembly as weighed, items scheduled for installation after weighing, tare, documentation status (drawing, revision, engineering order complied with, waivers, etc.), and a statement of accuracy claimed for the reduced MP.

LRB mass properties shall be provided by the Government in sufficient detail to enable total vehicle mass property predictions.

3.2.2.3 LRB Size. TBD

3.2.2.4 LRB Ullage Volume. The LRB shall provide a nominal tank ullage volume of (TBD) percent of the LO2 Tank and (TBD) percent of the fuel tank loaded propellant volume when pressurized to the upper limit of the pressure regulation band.

3.2.3 Reliability.

3.2.3.1 Flight Vehicle Subsystem Functional Reliability. The redundancy requirements for all flight vehicle systems (except primary structure, thermal protection system, and pressure vessels) shall be established on an individual subsystem basis, but shall not be less than fail-safe. The LRB shall meet the reliability requirements specified in NHB 5300.4 (1D-2).

3.2.3.2 Primary Structure, Thermal Protection, Pressure Vessels. The primary structure, TPS, and the pressure vessels subsystems shall be designed to preclude failure by use of adequate design safety factors, relief provisions, fracture control or safe life, and/or fail-safe characteristics.

3.2.3.3 Redundancy Verification. Redundant functional paths or subsystems shall be designed so that their operational status can be verified during ground turnaround without removal of Line Replaceable Unit (LRUs). In addition, these redundant functional paths of subsystems shall be designed so that their operational status can be verified in flight to the maximum extent possible, but as a minimum shall provide capability for redundancy management in the event of a malfunction of a functional path and shall provide information regarding redundancy status of the affected system sufficient to determine if a failure has occurred and if an abort decision is required. Exceptions to the inflight verification requirement of redundant functional paths include:

a. Standby redundancy (redundant paths where only one path is operational at any given time).

b. All functional paths of any subsystem which is inoperative (during such inoperative periods).

c. Pyrotechnic devices

d. Mechanical Linkage

Redundancies within a functional path shall be so designed that their operational status can be verified prior to each installation into the vehicle.

3.2.4 Maintainability. The LRB shall meet the maintainability requirements provided for in NSTS 07700 Volume XII and NHB 5300.4 (1D-2).1.

3.2.4.1 Accessibility. The LRB subsystems design shall provide access to each area of the LRB containing components or items requiring access. This access and clearance envelope shall permit the use of access and handling equipment if such GSE is required. Access design shall provide for the personnel requirements set forth in 3.3.9.

3.2.4.2 Replacement Time. The LRB shall be designed to permit replacement of defective LRUs within the minimum practicable time. The times to remove and replace the LRUs shall be identified and be demonstrable. The time required to replace the defective LRU commences when the defective unit has been identified and ends when the LRU has been installed and found to be flight worthy. Removal and replacement of LRUs will be accomplished during initial assembly or in the Vehicle Assembly Building (VAB) at KSC, or with station set V31 at VAFB. Contingency access will be available to the LRB engines and aft IEA, while the vehicle is on the pad. Access to the LRB forward area will be required in accordance with the requirements of 3.2.6.7.3.

3.2.4.3 Location. The LRB subsystems shall be so designed so that equipment is located in areas that minimize the requirements for provisions (platforms, swing arms, etc.).

3.2.4.4 Arrangement. The LRB subsystem components shall be arranged to permit close proximity of units relating to a particular subsystem for convenience in testing and trouble shooting. Arrangement schemes should enhance the capability to meet the operational turnaround flow.

3.2.4.5 Modular Packaging. Subsystem equipment shall be designed to satisfy the LRU definition. The following criteria shall be used to define LRUs.

a. It can be verified as ready for installation in an offvehicle environment.

b. After installation readiness verification, it can be installed in any vehicle without regard to serial number.

c. The installation does not require manufacturing-type tooling.

d. It does not require engineering support during normal installation or removal.

e. It requires less total costs than its next assembly for installation and removal.

The LRU determination shall be compatible with relative equipment failure rates and redundancy requirements.

3.2.4.6 Servicing. The LRB subsystems shall be capable of being serviced without a permanent fluid attachment to the launch pad.

3.2.4.7 Subsystem Checkout Connections. Electrical and fluid-handling subsystems shall include ground checkout test points which will permit normal planned subsystem checkout tests to be made without disconnecting tubing or electrical connectors which are normally connected in flight with the exception of the criticality 1R NSI-1 initiators.

3.2.4.8 Installation. The LRB subsystem components that require hoisting or lifting devices for installation shall be designed to be self aligning.

3.2.4.9 Handling. The LRB assemblies and support equipment shall be designed with the following features:

a. Attachment points and hardware shall be removable.

b. Loose hardware associated with handling equipment shall be permanently tethered to the prime unit.

c. Provisions will be made for support equipment to hoist and position LRUs weighing more than 90 pounds. Handholds and handles will be provided for components weighing more than 45 pounds which are not provided with GSE hoisting provisions. Weights shall be factored by installation position (see MIL-STD-1472).

3.2.5 Operational Availability.

3.2.5.1 Useful Life. Useful life for subsystems of the LRB shall be TBD.

Subsystem or Item	Minimum Number of Uses

3.2.5.2 Notification for Launch. With the flight vehicle mated and ready for transfer to the pad, the LRB shall be capable of launching within 26.5 hours.

3.2.5.3 Launch from Standby. The LRB shall have the capability to launch within four hours during a 24-hour standby status on the launch pad.

3.2.5.4 Launch Recycle. The LRB shall be capable of recycling to a TBD time before launch in the countdown, in the event of an SSME shutdown prior to LRB ignition.

3.2.5.4.1 Twenty-four Hour Scrub/Turnaround. The LRB shall be capable of launching within 24 hours after scrubbing a launch attempt. Scrub may occur any time prior to H2 igniter ignition.

3.2.5.5 On-Pad Stay Time. The LRB shall be capable of holding on the pad without GSE support for up to TBD days during the operational phase. The operational LRB configuration shall be supported by pad access or GSE support during the operations phase in order to hold on the pad for up to TBD calendar days.

3.2.5.6 Debris Protection (See 3.2.1.4.3.1). The LRB, including the ground systems, shall be designed to preclude the shedding of debris during prelaunch and flight operations that would jeopardize the flight crew and/or mission success. Note: Debris is defined as "broken, scattered remains emanating from the exterior surface(s) of any element."

3.2.6 Safety. The LRB Safety Program shall be in accordance with NHB 5300.4 (1D-2) at KSC or MIL-STD-1574 at VAFB as implemented by the LRB Safety Plan.

3.2.6.1 Hazard Reduction Precedence Sequence. Hazard elimination or control during all phases of the LRB life cycle shall be accomplished in the following order of precedence:

3.2.6.1.1 Design for Minimum Hazard. The major goal throughout the design phase of the LRB and its associated equipment, facilities and tooling shall be to insure inherent safety to the extent possible through the selection of appropriate design features such as fail operational/fail safe combinations and appropriate safety factors. Hazards shall be eliminated by design if possible, or, where complete elimination is impossible, shall be reduced to the lowest practical level of risk through design. Damage control, containment and isolation of potential hazards shall be included in design considerations. Safety checklists, consisting of lessons learned on prior programs and compendia of safe design practices, shall be used to evaluate designs for safety and to require changes where warranted.

3.2.6.1.2 Safety Devices. Known hazards which cannot be eliminated through design selection shall be reduced to a minimum acceptable level through the use of appropriate safety devices as part of the system, subsystem, or equipment. Such safety devices shall conform to the same standards of reliability and quality as the systems with which they are associated.

3.2.6.1.3 Warning Devices. Where it is not possible to preclude the existence or occurrence of a known hazard, devices shall be employed for the timely detection of the condition, or the potential for creation of such condition due to operator input, and the generation of an adequate warning signal. Warning signals and their application shall be designed to minimize the probability of wrong signals, misinterpretation of the warning, or of improper or inappropriate personnel reaction to the signal.

3.2.6.1.1.4 Special Procedures. Where it is not possible to reduce the magnitude of existing or potential hazard through design or the use of safety and warning devices, special procedures shall be developed to counter hazardous conditions for enhancement of ground and flight crew safety. Personnel training programs shall be conducted as necessary to inform operations personnel of the nature of the hazard, and in the proper use of the specified procedure in controlling it. Precautionary notations shall be standardized. Hazard reduction by procedure shall include necessary and appropriate controls for verification and approval of the procedural document prior to implementation, and controls and methods for verification that personnel activity does, in fact, follow the procedural document.

3.2.6.1.5 Safety Equipment. Where the existence of a hazard is inherent in a procedure and operation, and all of the aforementioned hazard reduction steps do not control the hazard to an acceptable level of risk, safety equipment shall be used to protect personnel or equipment. Training shall be conducted as necessary to insure that such safety equipment is used correctly to control the hazard.

3.2.6.2 Human Performance/Human Engineering. Safety related human engineering principles shall be applied during design, development, manufacture, test, maintenance, and operation of the LRB and associated equipment, facilities and tooling to minimize tht potential for creation of hazards through human error.

3.2.6.2.1 Human Engineering Design Criteria. The guidance contained in MIL-STD-1472 shall be applied to the design of the LRB and its associated equipment, tooling and facilities.

3.2.6.2.2 Automatic Control Override. Crew override capability shall be combined with appropriate caution, warning and system status displays to allow the flight crew to override automatic operations of the LRB where hazardous conditions would otherwise result, such as abort initiation.

3.2.6.3 Materials. All materials shall be selected in accordance with the LRB Materials and Processes Control Plan to insure that materials characteristics do not present hazards to personnel or equipment in their intended use or environment.

3.2.6.3.1 Hazardous Materials and Components. Hazardous materials and components (i.e., fuels, oxidizers, pyrotechnic devices) shall be transported, stored, used, handled, and maintained in a manner that will not constitute a hazard to personnel, the flight vehicle, equipment, payloads, the environment, and/or the mission.

3.2.6.4 Isolation of Hazardous Conditions. Provisions shall be made to physically isolate or separate hazardous, incompatible subsystems, materials, or environments. Designs shall consider space flight hazardous conditions identified in MSC-00134.

3.2.6.4.1 Structures. Structures shall be designed using manned aerospace design practices and principles.

3.2.6.4.2 Access. Access doors, covers, or hatches which are not removable shall be self supporting when open. Handles and controls for mechanisms such as hatches, access doors and platforms shall be designed with sufficient clearance to prevent injury to fingers and hands.

3.2.6.4.3 Lifting and Attach Points. All lifting, jacking, and attach points required for connection of lifting and handling fixtures or tools shall be identified on the flight hardware.

3.2.6.4.4 Fasteners. Failure of any single fastener for a line or cable that will cause loss of mission of vehicle will be identified and documented in the Critical Items List (CIL).

3.2.6.4.5 Fluid Removal. Capability to permit the removal or purging of all contained fluids shall be provided for all ground operations.

3.2.6.4.6 Connectors. System fittings, flanges and fluid connectors shall be keyed or restricted so that it is physically impossible to connect an incompatible component, commodity or pressure level.

3.2.6.4.7 Draining. The design of LRB pressure vessels shall not restrict gas ullage inflow to the extent that it will cause collapse or other degradation of the vessel when liquid is drained from it at the maximum permissible rate.

3.2.6.4.8 LRUs. LRB systems shall be designed so that it is physically impossible to install LRUs in a position or configuration other than that in which it is intended to function.

3.2.6.4.9 Pressure Vent and Relief. LRB fluid system design shall preclude relief system isolation with propellants loaded.

3.2.6.4.10 Propellants Vents. Separate lines and systems shall be used to vent each propellant system.

3.2.6.4.11 Pressure Controls. All adjustable pressure control devices shall have prominent markings to indicate the direction of pressure increase/decrease adjustment.

3.2.6.4.12 Enclosed Spaces. Relief protection shall be provided in sections where cryogens could be trapped as the result of leakage or otherwise. All compartments, voids, or other such spaces shall be vented as required to preclude collapse or burst due to differential pressure resulting from the environments specified in paragraphs 3.2.7.1 and 3.2.7.2.

3.2.6.5 Protection of Critical Functions. LRB subsystems shall be designed to prevent inadvertent or accidental activation or deactivation of safety-critical functions or equipment, which would be hazardous to personnel or vehicles during flight and ground operations.

3.2.6.6 Battery Protection. LRB batteries shall be isolated and/or provided with safety venting systems and/or explosion protection.

3.2.6.7 Range Safety Requirements. The LRB Flight Termination system shall comply with requirements of JSC 08060, KSC KMI 1710.1, ESMCR 127-1, WSMCR 127-1, 10A050562, 16A03039, and 3090506. At VAFB, the requirements of WSMCR 127-1 and applicable portions of MIL-STD-1574 and MIL-STD-454, Requirement 1 shall apply.

3.2.6.7.1 Destruct Safing. The LRB destruct systems shall be safed electronically and mechanically prior to normal LRB separation by an automatic signal from the Orbiter so that destruct action cannot occur. The mechanical safing shall provide a physical interruption of the ordnance train.

3.2.6.7.2 Command System. The flight termination system radio command system shall utilize a separate, secure flight code for each ARM and fire command so configured that continuous transmission of unauthorized correctly structured random formats for 30 minutes would allow not more than 1 chance in 10^6 of a valid command being accepted. The operational ground and flight codes shall be classified and preflight testing shall be accomplished without radiating the operational codes.

3.2.6.7.3 Forward T-24 Hour Access. Routine access shall be provided to the LRB at approximately T-24 hours for (a) insertion of the secure range safety flight code, and (b) making final electrical connections to the ordnance systems.

3.2.6.8 Static Electrical Protection. An LRB shall incorporate means of discharging electrical potential difference between the LRB and other interfacing elements, and between interfacing elements within the LRB. Black box cases shall be bonded to the LRB structure.

3.2.6.9 System Protection During Separation. Systems or equipment which are severed or disconnected during mission events (e.g., staging) shall not degrade mission success or crew safety.

3.2.6.10 Ordnance/Pyrotechnic Safety. The LRB S&A device shall have the capability of being remotely safed or armed from the launch control center through the Orbiter data bus and LRB MDM. Verification of LRB safing shall be provided during ground operations, including prelaunch assembly, recovery, retrieval, and refurbishment.

3.2.6.11 Contamination. Design, manufacturing, handling, and operational concepts shall, as a minimum, conform with the contamination requirements set forth in 3.3.5.

3.2.6.12
Cross-Contamination. Cross-contamination of LRB subsystems elements, such as LRB separation subsystem plume impingement on the Orbiter, shall be minimized.

3.2.6.13 S&A. An indication of the LRB S&A shall be provided.

3.2.6.14 Arming/Disarming Explosives. Provisions shall be made for arming ordnance devices as near to the time of expected use as is feasible. Provisions shall be made to disarm ordnance devices when no longer needed.

3.2.6.15 Separation of Critical Functions. Alternate or redundant means of performing a critical function shall be physically separated or protected such that an event which causes the loss of one means of performing the functions will not result in the loss of alternate or redundant means. These requirements do not apply to the safing and arming device used on the LRB ignition system.

3.2.6.16 Protection of Redundant Components. Redundant components susceptible to similar contamination or environmental failure causes such as shock, vibration, acceleration, or heat loads shall be physically oriented or separated to reduce the chance of multiple failure from the same cause(s). This requirement is waived for the Rate Gyro Assemblies.

3.2.6.17 Isolation of Subsystem Anomalies. Isolation of anomalies of critical functions shall be provided such that a faulty subsystem element can be deactivated either automatically or manually without disrupting or interrupting alternate or redundant functional paths or functions of other subsystems which would cause a Criticality 1 or 2 condition. During ground operations, capability to fault-isolate critical functions to the line replacement unit or group of units, without disconnections or use of carry-on equipment, shall be provided.

3.2.6.18 Facility Grounding. Each LRB shall be grounded to the facility ground in both the assembly area and the launch pad.

3.2.6.19 Drain, Vent, and Exhaust Port Design. LRB drains, vents, and exhaust ports shall prevent exhaust fluids, gases, or flames from creating hazards to personnel, vehicle, equipment or the environment.

3.2.6.20 Pressure Vessel Protection. Pressure vessels shall be protected against overpressurization or underpressurization which could be hazardous to personnel or the LRB.

3.2.7 Environment.

3.2.7.1 Natural Environments. The LRB and subsystems shall be designed to withstand (or be protected from) all natural environments defined in SE-019-043-2H and NSTS 07700, Volume X, Appendix 10.10 and NASA TM 82473, 1982 Revision.

3.2.7.2 Induced Environments. The LRB and subsystems shall be designed to withstand (or be protected from) all induced environments as defined TBD.

3.2.7.3 General. The LRB and subsystems shall be designed to withstand or be protected from moisture, dust, and rodents.

3.2.8 Transportability/Transportation. The LRB and its components shall be capable of being handled and transported from the fabrication site to all using sites without degradation.

a. The size and weight of the LRB components shall not exceed the limitations of the transportation system (TBD).

b. Design loads for the LRB will be based on prelaunch and flight requirements. Transportation loads shall not exceed design conditions. For new designs refer to MSFC-HDBK-505.

c. Thermal transportation environment shall not dictate design of the LRB or its components.

3.2.8.1 Tie-down Capability. Adequate capability shall be provided to permit the hardware to be secured to the transport vehicle, device, or container by bolting, blocking, strapping, or other feasible means.

3.2.8.2 Integral Protective Capability. The LRB design shall incorporate protection provisions to components which are highly vulnerable to damage during transport and handling.

3.2.9 Storage.

3.2.9.1 LRB Storage Life. TBD

3.3 Design and Construction Standards.

3.3.1 Selection of Specifications and Standards. All materials, parts, and processes shall be defined by standards and specifications. Selection of specifications, parts, and processes not specified herein shall be in accordance with MIL-STD-143.

3.3.2 General.

3.3.2.1 Materials, Parts, and Processes.

3.3.2.1.1 Materials and Processes. TBD

3.3.2.1.2 Pyrotechnics. All pyrotechnics, including associated electrical circuits and avionics shall comply with the provisions of JSC 08060.

3.3.2.2 Parts Selection.

3.3.2.2.1 Hardware Selection. Off-the-shelf equipment shall be used whenever possible. Development of new equipment shall be minimized. The design of the LRB shall provide for maximum efficiency of equipment selection and/or development through multiple applications of common items. Common items and their applications shall be identified, selected, and implemented in accordance with the commonality requirements of NSTS 07700, Volume VII. Items are listed in Table III.

TABLE III COMMON HARDWARE LIST

TBD

3.3.3 Electrical.

3.3.3.1 Electromagnetic Compatibility and Lightning Protection. LRBs shall meet requirements of SL-E-0001. The LRB shall be designed in accordance with JSC 07636 for both direct and indirect effects of lightning. Subsystem and/or individual equipment shall meet the requirements of the following documents:

a. SL-E-0002
b. MIL-STD-462

c. MIL-STD-463
d. JSC 07636

The subsystem and/or individual equipment requirements are not applicable to the ground system procurements unless specifically required by the procuring activity to meet the requirements for Electromagnetic Interference (EMI) critical equipment as defined in SL-E-0001.

3.3.3.2 Deadface Provisions. All wires that are powered from LRB batteries and are routed through the LRB/orbiter interface cables, shall be deadfaced in response to orbiter command by the LRB prior to disconnecting the cables during separation.

3.3.3.3 Electrical Bonding. Electrical bonding shall be in accordance with MIL-B-5087 in all areas, except in the area of lightning protection where the requirements of JSC-07636 shall apply.

3.3.3.4 Grounding and Isolation.

3.3.3.4.1 Primary Power Isolation. Grounding of all electrical/ electronic circuitry which receives its power across the LRB-to-Orbiter interface shall be referenced to the Orbiter grounding system. Each LRB power return shall be received through the LRB/Orbiter interface and will be isolated from structure, each other, and all other returns by a minimum dc resistance of 50K ohms prior to connection of the LRB single point ground.

3.3.3.4.2 Battery Power Isolation. Each battery circuit shall be referenced to its own single point ground system located in the LRB. Battery returns will be isolated from structure, each other, and all other returns by a minimum dc resistance of 50K ohms prior to connection of the LRB single point ground.

3.3.3.4.3 Secondary Power Isolation. Secondary power system returns may be grounded at one vehicle ground point per circuit. Secondary returns shall be isolated from structure, each other, and all other returns by a minimum dc resistance of two megohms prior to connection of its vehicle ground point. The vehicle ground point is a single point ground for that circuit only.

3.3.3.4.4 Load Isolation. Each individual "Black Box" or load that is connected to the main power bus shall have a minimum dc resistance of two megohms from input power leads to the unit case prior to external electrical connection.

3.3.3.4.5 Signal Isolation. Signal returns within a black box shall be isolated from unit case by at least two megohms prior to external electrical connection.

3.3.3.4.6 Single Point Ground (SPG). Autonomous power sources, within common returns, shall be grounded at one point only at any given time. The conductor from the main power return to the SPG shall be capable of carrying any fault current which may occur. The SPG shall not be used intentionally as a normal circuit current carrying path.

3.3.3.4.7 Static Grounding. All structural elements of the LRB shall be electrically bonded together. The preferred method of "Black Box" case bonding is such that the case is connected with the LRB structure through low-impedance metal-to-metal conductive mounting surfaces. If shock mounts or thermal isolation prevents this, wide flat short bonding jumpers may be used to conform to bonding specification MIL-B-5087.

3.3.3.5 Bypass Circuit Interfaces. Bypass circuits used during onboard checkout shall not disable system pressurization relief mechanisms.

3.3.3.6 Redundant Electrical Circuits. Redundant electrical circuits shall not be routed through the same connector. Also, redundant connectors or paths for electrical wiring (i.e., for pyros) shall be so located that an event which damages one path is not likely to damage another.

3.3.3.7 Isolation of Test/Monitor Points. Isolation between test/monitor points and internal circuits shall be such that a test/monitor point short to ground shall not degrade the equipment.

3.3.3.8 Electrical Circuit Routing. Electrical circuits shall not be routed through adjacent pins of an electrical connector if a short circuit between them would constitute a single failure that could cause loss of the critical function. In addition, shorting springs or clips shall not be used in operational electrical/electronic connectors.

3.3.3.9 Electrical Circuit Disconnect. Electrical circuits which are to be disconnected or cut in the normal course of mission event (e.g., vehicle separation) shall be protected against short circuiting or compromising of other circuits during the remaining phases of the mission.

3.3.3.10 Inadvertent Electrical Shorting Due to Debris. Malfunction or inadvertent operation of vehicle electrical or electronic equipment caused by exposure to conducting or nonconducting debris or foreign materials shall be prevented by design.

3.3.3.11 Protection of Electrical and Electronic Devices. Electrical and electronic devices shall incorporate protection against reverse polarity and/or other improper electrical inputs during qualification, acceptance, and checkout tests, where such inputs could cause mission significant damage to the devices that would not be immediately and unmistakeably apparent. If it is impractical to incorporate adequate protection as a part of the vehicle device, protection shall be provided externally by ground based equipment at the interface between the device and the ground test equipment.

3.3.3.12 Avoidance of Matched Pairs. Matched pair measurement system designs shall not be used (i.e., matched transducer-signal conditioner pairs).

3.3.3.13 Power Supply Protection. Independent power sources shall not be tied together by diodes, specifically, within black boxes.

3.3.3.14 Improper/Cross Connection Prevention. Connectors shall be designed to preclude improper mating and, where in close physical proximity to similar connectors, design shall preclude the capability of cross-connection.

Electrical connections shall be designed such that they can be mated without pin damage, and can be visually verified for proper installation. LRB electrical connections shall be sized or keyed to prevent cross connection.

3.3.3.15 Wire and Cable Installation. Wire and harness installation shall be designed so as to minimize potential damage. Wiring shall be protected by easily removable covers or other protective devices. Wiring shall be installed per MSFC-SPEC-494.

3.3.3.16 Circuit Boards. TBD

3.3.4 Mechanical.

3.3.4.1 Design Safety Factors. The factors of safety given in Table II shall be used for the LRB. Proof factors developed from fracture analyses are shown in Table (TBD).

3.3.4.2 Ultimate Combined Load. The external, thermally induced, and internal pressure loads should be combined in a rational manner according to the equations given in Table II, Note (2) to determine the design loads. Any other loads induced in the structure, e.g., during manufacturing, shall be combined. No load conditions outside the crew safety envelope shall be considered. In no case shall the ratio of the allowable load to the combined limit loads be less than the designated SF. These equations are applicable to either tension or compression loads. All structural components that are subject to compressive inplane stresses, including loads resulting from temperature changes, shall be investigated for buckling failure. The evaluation of buckling strength shall consider the combined action of primary and secondary stresses and their effects on (1) general instability, (2) local or panel instability, (3) crippling, and (4) creep. Design loads for buckling shall be ultimate loads. Loads tending to alleviate buckling shall not be increased by the ultimate factor of safety. Destabilizing limit loads shall be increased by the ultimate factor of safety although stabilizing loads shall not.

TABLE II
DESIGN FACTORS OF SAFETY

COMPONENT	FACTORS OF SAFETY ULTIMATE	FACTORS OF SAFETY YIELD
1. <u>General Structure</u>		
Limit Load		
o Well Defined	1.25	1.10
o Other	1.40	1.10
2. <u>Main Propellant Tanks</u>		
(a) Pressure Only		
o Limit Pressure	N/A	1.10
o Max Operating Pressure	1.25 to 1.40 (Note 1)	N/A
(b) Combined Pressure and Loads (See Note 2)		
o Limit Pressure	N/A	1.10
o Max Operating Pressure	1.25 to 1.40 (Note 1)	N/A
(c) Loads (Other Than Pressure)		
o Well Defined	1.25	1.10
o Other	1.40 (Note 1)	1.10
3. <u>Propulsion System</u>		
(a) Propellant Feed Lines and All Other Lines Greater than 1.5 in. Dia. Whichever is Critical		
o Limit Pressure	1.50	1.25
Or o Limit Load	1.40	1.10
(b) Lines Less than 1.5 in. Dia.		
o Limit Pressure	4.0	2.0
(c) Hydraulic & Pneumatic Lines, High Pressure Vessels, Actuating Cylinders, Valves, Filters, and Switches		
o Limit Pressure	2.0	1.5

NOTES:

1. Ultimate Factor of Safety application
   Use Factor of Safety = 1.25 for well defined loads.
   Use Factor of Safety = 1.40 for all other loads.
   The equivalent Factor of Safety (Eq. F. S.) is derived by the equation:

   $$\text{Eq. F.S.} = \frac{1.25\ (\text{well defined loads}) + 1.40\ (\text{all other loads})}{\text{Total Loads}}$$

   Eq. F.S. must be between the limits 1.25   Eq. F.S.   1.40.
   Should the Eq. F.S. exceed 1.40, the total limit load will be multiplied by a F.S. 1.40. Should the Eq. F.S. be less than 1.25, the total limit load will be multiplied by F.S. = 1.25.

2. Ultimate Combined Load Equations-Loads induced in the LRB structure shall be combined according to the following equations:

   a. K1 (L well defined) + K2 (L thermal) + K3 (L pressure) + K4 (L dynamic) Σ 1.25 L.

   b. K1 = 1.25 for boost conditions when the term is additive to the algebraic sum, ΣL.

   c. K2 = 1.40 for conditions when the term is additive to the algebraic sum, ΣL.

   d. K3 - 1.25 for the main propulsion tanks when the term is additive to the algebraic sum, ΣL.

   e. K4 = 1.40 for aerodynamic loads and dynamic transient loads.

   f. K2, K3 = 1 when the term is subtractive to the algebraic sum, ΣL.

   g. L well defined = loads due to thrust, inertia from thrust and dead weight.

   h. L thermal = thermally induced loads.

   i. L pressure = maximum expected regulated pressure where additive to the algebraic sum, ΣL.

   J. L pressure = minimum expected regulated pressure when subtractive to algebraic sum, ΣL.

3.3.4.3 Allowable Mechanical Properties. Values for allowable mechanical properties of structural materials in their design environment, e.g. subjected to single or combined stresses, shall be taken from MIL-HDBK-5, MIL-HDBK-17, MIL-HDBK-23, or other sources approved by NASA. Where values for mechanical properties of new materials or joints or existing materials or joints in new environments are not available, they shall be determined by analytical or test methods approved by NASA. Complete documentation of testing and analyses used to establish material properties and design allowables shall be maintained by the contractor, and the documentation shall be made available to the procuring agency on request. When using MIL-HDBK-5, material "A" allowable values shall be used in all applications where failure of a single load path would result in loss of vehicle structural integrity. Material "B" allowable values may be used in redundant structure in which the failure of a component would result in a safe redistribution of applied loads to other load-carrying members.

3.3.4.4 Fracture Control. In addition to the factors of safety presented in 3.3.4.1, designs for primary structure including composite structure, glass components or other subsystems, and tanks shall consider the presence of sharp cracks, crack-like flaws, or other stress concentrations in determining the life of the structure for sustained loads and cyclic loads coupled with environmental effects. Parts determined to be fracture critical, including all pressure vessels, shall be controlled in design, fabrication, test, and operation. For the purpose of this paragraph, a pressure vessel is defined to be a component designed primarily for the storage of pressurized gasses or liquids. For new design, refer to MSFC-HDBK-505.

3.3.4.5 Fatigue. Safe life design shall be adopted for all major load carrying structures. These structures shall be capable of surviving without failure, a total number of mission cycles that is a minimum of four times (for low cycle), or ten times (for high cycle) greater than the total number of mission cycles expected in service. (Life cycle requirements in excess of 10,000 cycles are considered high.) This does not preclude fail-safe structural features. For new designs, refer to MSFC-HDBK-505.

3.3.4.6 Creep. The design shall preclude cumulative creep strain leading to rupture, detrimental deformation, or creep buckling of compression members during their service life. Analysis shall be supplemented by test to verify the creep characteristics for the critical combination of loads and temperature.

3.3.4.7 Temperature. The effects of temperature extremes specified in 3.2.7.2 shall be considered in the design of the structure of the LRB. Thermal design shall be based on the nominal heating environments. Off-nominal assessments shall be performed and incorporated as a design requirement only when the resultant analysis shows a critical condition exists.

3.3.4.8 Load Conditions. The stresses developed in structural members shall be established and shall be accounted for from all load sources that act in combination at any point in the mission profile, with due regard being given to the probability and simultaneity of the occurrence. Acceptable statistical procedures shall be used in the treatment of load sources having statistical variation.

3.3.4.8.1 Load and Internal Pressure Combination. When internal pressure effects in combined load conditions are stabilizing or otherwise beneficial to structural load capability, the minimum limit internal operating pressure or minimum regulated pressure for that condition shall be used for design instead of the ultimate internal pressure.

3.3.4.9 Aeroelasticity. Static and dynamic structural deformations and responses including the effects of aeroelasticity under all limit conditions and environments shall be accounted for in the design of the LRB and shall not cause a system malfunction, preclude the stable control of the vehicle, or cause unintentional contact between adjacent bodies.

3.3.4.10 Stress Concentration. Appropriate stress concentration factors shall be applied in stress analysis.

3.3.4.11 Misalignment and Tolerances. The effects of allowable structural misalignments, control misalignments, and other permissible and expected dimensional tolerances shall be considered in the analysis of all loads, load distributions, and structural accuracy. For establishing allowable stresses and critical design stresses, a statistical combination of design tolerances shall be used.

3.3.4.12 Design Thickness. Stress calculations of structural members, critical for stability, shall use the mean drawing thickness or 1.05 times the minimum drawing thickness, whichever is less. Structural members, critical for strength, shall use the mean drawing thickness or 1.10 times the minimum drawing thickness, whichever is less. The wall thickness used in the stress calculations for pressure vessels shall be the minimum thickness shown on the drawing. The thickness for tension-critical and shear critical members shall be the minimum thickness. External panels shall be free of panel flutter at 1.5 times the local dynamic pressure at the appropriate temperature and mach number for all flight regimes including aborts.

3.3.4.13 Strength and Stiffness. The LRB structure, including pressure vessels and mechanical systems, shall have adequate strength and stiffness, at the design temperature, to withstand limit loads and pressures without loss of operational capability for the life of the vehicle and to withstand ultimate loads and pressures at design temperature without failure. The structure shall not be designed to withstand loads, pressures, or temperatures arising from malfunctions that prevent a successful abort. Major structural elements shall not be designed by nonflight conditions, i.e. conditions other than prelaunch (vehicle mating).

3.3.4.14 Pressurization. The LRB structural design shall include the effects of differential pressures within/between the components due to operational activities of ascent, separation, and reentry, as defined in 3.2.7.2.

3.3.4.15 Venting. Venting shall be provided in the LRB components to ensure that internal limit pressures are not exceeded. Venting shall also be provided in the LRB components and/or their shipping containers or pressure test fixtures to assure that the components will experience no external collapsing pressures during transportation or testing. The appropriate LRB cavities shall be vented to maintain a pressure differential which will not be detrimental to flight hardware.

3.3.4.16 Drainage. Where required, provisions shall be made in the structure to drain accumulated liquids, e.g. condensation, rainwater, or spills. The system shall provide for collection for disposal of drained hazardous materials.

3.3.4.17 Purging and Flushing. System design shall provide for purging/flushing of all plumbing and fluid components. Components which cannot be designed to satisfy this requirement shall be identified and shall use quick-disconnect mechanical and electrical interfaces to allow local flushing or removal for flushing.

3.3.4.17.1 Hazardous Gases. Provisions shall be made to prevent the accumulation of hazardous, i.e. toxic, explosive, flammable, or corrosive, gases and/or fluids in the LRB. In LRB closed volumes, including those that are purged, where there is a significant risk of hazardous gas accumulation, detection of hazardous gases shall be provided by means of sensing lines to the GSE analyzer to ensure that hazardous conditions do not exist during prelaunch and flight.

3.3.4.18 Flight Element Mating Design Characteristics. The joint concept for ET/LRB utilization shall provide for:

a. Assembly without internal access to the ET.

b. Assembly with access sufficient to:

   (1) Easily verify alignment of mating interface, and

   (2) Easily join (with positive engagement) the mating joint.

c. Assembly without requirement for makeup of explosive devices during mating.

d. Assembly allowing use of a nominal "0" moment joint in the ET interstage.

e. Assembly allowing unrestrained rotation in the orbiter/ET plane.

f. Assembly within the operational timeline.

g. Accommodating shrinkable induced loads caused by ET and LRB cryogenic loading and LRB expansion/shrinkage.

h. Restricting LRB pitch misalignments, both LRBs deflected symetrically, to $\pm 0.25^{\circ}$ maximum during launch and boost in flight, for aerodynamic performance and flight control considerations.

i. Restricting LRB yaw misalignments to $\pm 0.25^{\circ}$ maximum during launch and boost in flight, for aerodynamic performance and flight control considerations.

3.3.4.19 Leak Protection - External Ports. Servicing and test ports, not required to function in flight, shall be designed to preclude leakage in flight. If caps are used, the material shall be compatible with the applicable subsystem media and the expected environments.

3.3.4.20 Hydraulic Systems. Hydraulic systems design shall be in accordance with MIL-H-5440.

3.3.4.21 Flow Induced Vibration. All flexible lines and bellows shall be analyzed and designed to exclude or minimize flow induced vibrations in accordance with 20M02540.

3.3.4.22 Improper and/or Cross Connection Prevention. Fluid lines, fasteners, sockets, and like items shall be designed to preclude inadvertent interchanging of connection.

3.3.5 Contamination Control. Contamination of the LRB shall be controlled to assure system safety, performance, and reliability. Control shall be implemented by a coordinated program in accordance with SN-C-0005 from design concept through procurement, fabrication, assembly, test, storage, delivery, operations, and maintenance of the LRB.

Selection of the system design shall include consideration of materials compatibility, corrosion resistance, and sensitivity to contamination. Fluid systems design shall include self-cleaning (filtering) protection compatible with component sensitivity.

Wire cloth filters used in the LRB Flight Systems and at the flight systems/GSE interface shall conform to SE-F-0044.

Specific cleanliness levels in accordance with SN-C-0005 shall be established for materials surfaces, fluid systems, and functional items, as required for effective control of contamination.

Fluids required for manufacture, test, cleanliness evaluation, and operation of the LRB shall meet the purity, cleanliness, and analysis requirements of SE-S-0073. Design of the LRB structures and components shall minimize the necessity for special cleaning techniques, or hand cleaning during rework or modification operations.

3.3.5.1 Moisture and Fungus Resistance.

3.3.5.1.1 Moisture. The LRB structure shall provide moisture proof enclosures, as required, for the recovery, electrical, and instrumentation subsystems. All TPS material and installation design shall minimize absorption and entrapment of liquids or gases which would degrade thermal or physical performance or present a fire hazard (wicking), and shall not require draining, drying, or any dedicated purge system from refurbishment through launch.

3.3.5.1.2 Fungus. Materials which are nonnutrient to the fungi defined in MIL-STD-810, Method 508, shall be used. When fungus nutrient materials must be used, they should be hermetically sealed or treated to prevent fungus growth for the effective lifetime of the component. Materials not meeting this requirement shall be identified as a limited life component and shall identify any action required such as inspection, maintenance, or replacement periods. Fungus treatment shall not adversely affect unit performance or service life. Materials so treated should be protected from moisture or other environments that would be sufficient to leach out the protective agent. Fungus inert materials are listed in MIL-STD-454, Requirement No. 4.

3.3.5.2 Corrosion of Metal Parts.

3.3.5.2.1 Stress Corrosion. MSFC-SPEC-522 shall be used for design and materials selection for controlling stress corrosion cracking. Metals susceptible to stress corrosion cracking in the environmental of service conditions defined herein, shall not be used unless test data are furnished which indicate material suitability.

3.3.5.2.2 Corrosion Protection. Corrosion resistant metals shall be used wherever cost effective and practical. The use of dissimilar metals, finishes, and coating shall comply with the requirements of MSFC-SPEC-250.

3.3.6 Coordinate Systems. Coordinate systems for the LRB shall be in accordance with JSC-09084.

3.3.7 Interchangeability and Replaceability. The definitions of item levels, item exchangeability, models and related items, shall be in accordance with MIL-STD-280.

3.3.7.1 Line Replaceable Units. All LRUs which possess the same functional and physical characteristics as to be equivalent in performance, reliability, and maintainability shall be interchangeable.

3.3.7.2 Shop Replaceable Units. All shop replaceable units (SRUs) which possess the same functional and physical characteristics as to be equivalent in performance, reliability, and maintainability shall be interchangeable.

3.3.8 Workmanship. The LRB, including all parts and assemblies, shall be designed, constructed, and finished in a quality manner. Defective plating, painting, riveting, machine-screw assembly, welding, brazing, deburring, cleaning, and defective marking of parts and assemblies shall be cause for rejection. Manufacturing practices shall be followed that will produce equipment free of defects.

3.3.9 Human Performance/Human Engineering. The LRB design effort shall provide furnishings, equipment, workspaces, and access ways sized for personnel within the 5th and 95th percentile dimensional range of U.S. Air Force population, as extrapolated to the year 1980. MIL-STD-1472 shall be used as a guide for human engineering design criteria.

3.3.10 Manned Spacecraft Criteria and Standards. LRB flight and ground systems shall conform to the requirements of JSCM 8080 Standards.

3.4 Logistics. The logistics requirements and means for providing logistics support shall be as specified in TBD.

3.4.1 Design for Maintenance. The maintenance concept will be to "remove and replace" to the functional LRU level. "Repair-in-Place" may be accomplished only when justified by the results of the maintenance analysis, associated trade studies, and consideration of impact on turnaround requirements.

3.4.1.1 Levels of Maintenance. The three levels of maintenance are:

Level 1 - Organizational

Organizational maintenance includes preventive and corrective actions required to inspect, service, and clean LRB hardware, and remove and replace defective LRUs. LRUs removed during organizational maintenance are transferred to intermediate or depot level maintenance shops for repair/rebuild. At the organizational level, the maintenance concept is to remove and replace defective LRUs.

Level 2 - Intermediate

Intermediate level maintenance is performed in direct support of organizational maintenance and involves repair of LRUs by the removal and replacement of SRUs.

Level 3 - Depot.

Depot maintenance supports lower levels of maintenance by providing technical assistance and performing maintenance beyond the capability of organizational and intermediate levels. Depot maintenance capability requires equipment, facilities, and/or skills not economically available at organizational and intermediate maintenance levels. Depot level maintenance is performed by designated sources, e.g. manufacturers, NASA centers, and Department of Defense (DOD) depots.,

3.4.2 Facilities and Facility Equipment. Facilities and equipment will be required for handling and storage of spares, components, subassemblies and assemblies, and for maintenance and repair of failed items. A logistics facility analysis will be made to determine requirements. Existing facilities will be used to the maximum extent.

3.5 Personnel and Training. The design shall consider tasks to be accomplished by operating, test, and maintenance personnel. Considerations should include safety, accessibility, critical tasks, complexity, and necessity for training.

3.6 Interface Requirements. (TBD)

3.6.2 Interproject.

3.6.1.1 Functional Interfaces. (TBD)

3.6.1.2 ET/ILRB Interfaces. (TBD)

3.6.1.3 Orbiter/ILRB Interfaces. (TBD)

3.6.1.4 Space Shuttle Vehicle/MLP-VAB Facilities Interfaces. (TBD)

3.6.1.5 Space Shuttle Vehicle/MLP-Launch Pad Interfaces. (TBD)

3.6.1.6 Flight Vehicle/Launch Processing System (LPS) Computational System's Interface. (TBD)

3.6.1.7 LRB Receiving and Checkout Station. (TBD)

3.6.1.8 Moldline and Protuberance. (TBD)

3.6.1.9 LRB to Retrieval Station. (Deleted)

4.0 REQUIREMENTS - CEI, LRB ENGINE

4.1 Functional Performance Requirements

4.1.1 Thrust. The engine shall operate in accordance with Table 1, (TBD) at full power level, rated power level and minimum power level.

4.1.1.1 Thrust Level Change. The engine shall be capable of changing thrust between the Full Power Level and Minimum Power Level in response to step commands in thrust level of (TBD) percent of RPL or multiples thereof.

4.1.1.2 Engine Calibration. (TBD)

4.1.1.3 Thrust Tolerance. (TBD)

4.1.2 Mixture Ratio. (TBD)

4.1.2.1 Mixture Ratio Tolerance. At steady-state, the engine shall operate at a mixture ratio of (TBD).

4.1.3 Engine Specific Impulse. (TBD)

4.1.4 Engine Gimbaling Capability. (TBD)

4.1.5 Pressurization Gas. (TBD)

4.2 Operation Requirements

4.2.1 Engine Start. The engine shall be capable of starting, upon receipt of an electrical command signal from a source external to the engine. The engine shall only be commanded to start to RPL.

4.2.1.1 Propellant Conditions for Start. The engine shall be capable of accepting a start command provided the engine propellant inlet conditions are (TBD).

4.2.1.2 Engine Start Sequence. The engine shall provide self-contained control of its start sequence.

4.2.1.3 Engine Start Time. (TBD)

4.2.1.4 Engine Start Rate. (TBD)

4.2.1.5 Engine Start Impulse. The engine design shall maximize the effective specific impulse of the propellant consumed from start command to commanded power level.

4.2.1.6 Engine Starts. The engine shall be capable of starting once after each ground servicing.

4.2.2 Engine Shutdown. The engine shall be capable of shutdown from any defined power level upon receipt of an electrical command signal.

4.2.2.1 Engine Shutdown Time. The engine shall be capable of shutdown within the requirements of (TBD).

4.2.2.2 Engine Shutdown Rate. The engine shall be capable of shutdown from any defined power level upon receipt of an electrical command signal at a rate which is no greater than (TBD) lbs thrust change per any ten (10) milliseconds time interval.

4.2.2.3 Engine Shutdown Impulse. The engine shutdown impulse and shutdown impulse variation shall be (TBD). The amount of propellant consumed to zero thrust shall be (TBD).

4.2.2.4 Engine Shutdown During Engine Start. The engine shall be capable of shutdown at any time during the start sequence.

4.2.3 Thrust Level Response. (TBD)

4.2.4 Engine Duration. The engine shall be capable of functioning with the following durations:

4.2.4.1 Continuous Run Duration. (TBD)

4.2.4.2 Full Power Level Run Duration. (TBD)

4.2.4.3 Prelaunch Service Free Duration. The engine shall be capable of functioning at any time without ground servicing under propellant loading conditions within a period no greater than 24 hours.

4.2.4.4 Prelaunch Conditioning Duration. (TBD)

4.2.4.5 Engine Controller Operational Duration. The engine controller and sensors shall be designed to function in an ambient temperature as specified in NSTS 07700, Volume X, Appendix 10.10 and SD74-SH-0144 (Para. 2.4.1.4, 3.1.4, and 3.2.4) for an unlimited period of time during checkout and maintenance with or without propellants loaded. The controller shall be designed to function without degradation in the vibroacoustic environment (TBD).

4.2.5 Monitored Redlines. The engine shall not require monitoring external to the engine of any parameter as a prestart redline other than the prelaunch purge sequence time durations, hydraulic pressure, valve leakage detection temperatures, and an engine ready signal. The conditions required to achieve a prestart engine ready signal shall be as specified in (TBD). The engine shall be capable of functioning with all critical parameters monitored by the engine control system.

4.2.6 Engine Generated Low Frequency Thrust Oscillations. (TBD)

4.2.7 Combustion Stability. (TBD)

4.2.8 Surface Temperatures. (Deleted)

4.2.9 Propellant Dumping Restrictions. (TBD).

4.2.10 System Checkout and Monitoring Capability. The design shall include onboard checkout capability, redundancy verification, and status monitoring for systems verification during ground and flight operations. Sections 1.0, 2.0, and 3.0 of 40M35772 shall be used as a guideline during onboard checkout and monitoring analysis. The design shall include rapid fault isolation techniques which activate or deactivate subsystem components without unduly disturbing other subsystems or components. The engine design shall include a Limit Control system capable of automatically adjusting power level or initiating engine shutdown to prevent catastrophic failure. The Engine Limit Parameters are specified in TBD. The limit Control System shall be active subsequent to the receipt of a "Limit Control enable" command from the vehicle, and shall be inactive subsequent to the receipt of a "Limit Control inhibit: command from the vehicle. If an engine shutdown is prevented by a vehicle command, the requirements of 4.1, 4.2, and 4.6 shall not be applicable.

4.2.11 Propellant Dump Capability. The engine shall be capable of simultaneously dumping residual propellants in both the liquid and gas phase. The engine shll be capable of dumping vehicle and engine residual propellants at the minimum engine flowrates.

4.2.12 POGO Suppression. (TBD)

4.3 Physical Requirements

4.3.1 Envelope. (TBD)

4.3.2 Engine Weight. (TBD)

4.3.3 Engine Alignment. the engine actual thrust vector shall be within 30 minutes of arc to the engine centerline and within 0.60 inch of the gimbal center. The gimbal center shall lie within 0.010 inch of the engine centerline.

4.4 Environmental Requirements. Unless otherwise specified in this document, the engine shall be designed to perform in the applicable natural environmental conditions defined in NSTS 07700, Volume X, Appendix 10.10.

4.4.1 Transportation, Storage

4.4.1.1 Ambient Conditions. The engine shall be capable of being transported and stored over an ambient temperature range as specified in NSTS 07700, Volume X, Appendix 10.10 an ambient pressure range of 15 psia to 2.5 psia, a relative humidity of 100% at temperatures less than or equal to 100°F, and a relative humidity of 100% referenced to a temperature of 100°F for the temperature range between 100° and 165°F.

4.4.1.2 Storage. The engine shall suffer no degradation of reliability or operating life during the storage period.

4.4.1.3 Ground Handling Loads. The engine shall be capable of withstanding handling loads as defined by SD73-SH-0069-2C (Para. 2.21.14) when the engine is installed in the engine handling frame or supported at the normal interface.

4.4.1.4 Exposure Conditions. The engine system and components shall be capable of being transported and stored without deterioration in areas where conditions may be encountered having salt spray and relative humidity as experienced in coastal regions. The engine system and components shall be capable of withstanding exposure to sand and dust, when equipped with proper closures. The use of fungus-nutrient materials shall be minimized.

4.4.2 Static Firing

4.4.2.1 Operating Environment. The engine shall be capable of operating in a single or multi-engine installation in any static firing environment equivalent to prelaunch and flight conditions defined in this document.

4.4.3 Exposure Conditions - The engine shall be capable of operating without degradation of reliability following exposure to salt spray and humidity as experienced in coastal regions. Components shall be capable of withstanding exposure to sand and dust, when equipped with proper closures.

4.4.4 Controller. Prelaunch - The controller shall operate without damage or upset to critical circuits in compliance with applicable requirements of JSC 07636, Space Shuttle Lightning Protection Criteria Document.

4.4.5 Launch Phase

4.4.5.1 Thermal Conditions. The engine shall be capable of operating without degradation of reliability after exposure to prelaunch phase thermal conditions and during exposure to launch phase thermal conditions specified in (TBD).

4.4.5.2 Vibration, Shock, Acoustic, Aerodynamic Loads. The engine shall be capable of withstanding without degradation of reliability, launch phase vibration, shock, acoustic and aerodynamic loads as specified (TBD).

4.4.5.3 Vehicle Applied Acceleration Loads. The engine shall be capable of operating without degradation of reliability when subjected to the acceleration values resulting from rigid body acceleration vehicle dynamics, and thrust structure dynamic response as (TBD).

4.4.5.4 Controller. The Controller shall be designed to operate without damage or upset to critical circuits in compliance with applicable requirements of JSC 07636, Space Shuttle Lightning Protection Criteria Document.

4.5 Interface Requirements. Interface requirements and characteristics for the engine shall be (TBD).

4.5.1 Gimbal Connect Point. The engine shall be designed to provide a gimbal assembly connect point for attachment to the stage in accordance with the requirements of 4.1.4.

4.5.2 Propellant Connect Points. (TBD)

4.5.3 (Deleted)

4.5.4 Electrical Connect Panel. All operational engine electrical connections, except the Nonflight Data Acquisition Connectors, shall be terminated at the electrical interface panel. The panel shall be provided by the engine, structurally supported by the stage, and fixed relative to the gimbal connect point. The electrical connector shall be receptacle type.

4.5.4.1 Nonflight Data Acquisition Connectors. The engine shall provide electrical connectors for monitoring internal engine parameters during static firing.

4.5.5 Gimbal Duty Cycle Capability. (TBD).

4.5.6 Fluid Requirements

4.5.6.1 Propellant. (TBD)

4.5.6.1.1 Engine Start Propellant Conditions. (TBD)

4.5.6.1.2 Engine Internal Prestart Propellant Conditions. (TBD)

4.5.6.1.3 Engine Operating Propellant Conditions. (TBD)

4.5.6.1.4 Engine Inlet Surge Pressure. (TBD)

4.5.6.1.5 Engine Inlet Line Characteristics. (TBD)

4.5.6.2 Pneumatics. Nitrogen in accordance with MIL-P-27401 and helium in accordance with MIL-P-27407 shall be used for operational and servicing purges and leakage tests, and shall be supplied to the engine. Air or gaseous nitrogen shall be supplied to the engine for controller cooling.

4.5.6.3 Pressurization Gas. (TBD)

4.5.6.3.1 Oxidizer Tank Pressurant. (TBD)

4.5.6.3.2 Fuel Tank Pressurant. (TBD)

4.5.6.4 (Deleted)

4.5.7 Electrical Requirements.

4.5.7.1 Power Requirements. The engine shall start, run and shutdown safely and provide satisfactory thermal conditioning of the controller when 115/200 VAC, 3 phase, 400 Hz power and 28 VDC power is provided by the vehicle. The 115/200 VAC and 28 VDC power circuits shall be dual redundant.

4.5.7.2 Flight Data Acquisition. The engine shall supply data to the Orbiter vehicle.

4.5.7.3 Nonflight Data Acquisition. Parameters acquired through the nonflight data acquisition connectors shall consist of and be limited to the output prior to digital conversion, of selected engine mounted flight sensors as indicated in (TBD). The design of the nonflight data acquisition connectors shall preclude interaction between the system external to the connector and internal functions of the engine controller.

4.5.7.4 Vehicle/Engine Electrical Interface. The engine shall accept commands from the vehicle.

4.6 Reliability Service Life.

4.6.1 Engine Reliability and Service Life. (TBD)

4.6.2 Overhaul. The engine shall be capable of being overhauled, i.e., disassembled, inspected, repaired and re-assembled following service or damage. The overhauled engine shall be capable of acceptance test.

4.6.3 Failsafe Design. (TBD)

4.6.3.1 Combustion Stability. (TBD)

4.7 Design Consideration.

4.7.1 Structural Loads. The SSME shall be designed to comply with the structural loads specified in TBD.

4.7.1.1 Structural Criteria. The engine shall be designed to provide the following minimum factors of safety.

Minimum yield factor of safety is 1.10.

Minimum ultimate factor of safety is 1.40.

The above factors of safety shall apply to engine and components under the most critical expected conditions of operation, including FPL and the combined effects of all vibratory acoustics, thermal, tolerance buildup and surging. Where higher factors of safety are defined elsewhere in this specification, they will be the defining criteria. The engine structure or components shall not experience stress in excess of the minimum guaranteed ultimate strength at the ultimate factor of safety times the maximum load. The structure shall not experience stress in excess of the minimum guaranteed yield strength at the yield factor of safety times the maximum load. However, local yielding is allowed provided it is limited and is not detrimental to proper engine operation. Loads and environments shall be determined from conditions specified herein.

The engine and components shall be designed to demonstrate analytically or by test and the safety factor criteria of 4.7.1.1 and 4.7.1.2 can be met at end of specified service life.

4.7.1.1.1 Material Properties and Design Allowables. The engine structure shall be designed employing material properties based on MIL-HDBK-5 ("A" Basis) or other basis or sources to be authorized by the Procuring Activity. The minimum guaranteed values shall be used for mechanical properties (strengths) and typical or mean value for physical properties. When applicable data is not available, properties for a particular material shall be established by test or based on available literature research and/or engineering experience.

Material design allowables shall include all environmental effects to which the material will be exposed from fabrication through flight, and the yield strength shall be the 0.2 percent offset value. The contractor shall maintain complete documentation of testing and analyses used to establish the material properties and design allowables, and the documentation shall be made available to the Procuring Activity upon request.

In particular, failure strains shall be established with respect to temperature, cyclic load, sustained load, and shock (both mechanical and thermal due to heating and chilling). The sensitivity of an engine component to flaw fracture, and stress corrosion, under operating conditions shall be rigorously established, particularly for weldments, castings and brazed elements.

4.7.1.2 Special Structural Verification Criteria. All components found to be fracture critical shall be subjected to a fracture life verification analysis. The fracture mechanics analysis shall demonstrate that any crack-like flaw not detected by either proof testing or NDE (nondestructive evaluation) will not grow to critical size and cause failure during the engine service life times the required factor.

Engine components shall be designed for the following minimum verification pressures unless otherwise specified:

Definition of pressure terms and factors:

Limit Pressure - The limit pressure is the 2 sigma operating pressure including the effects of system environment such as vehicle acceleration and pressure transients.

Proof Pressure - The pressure that a pressurized component must sustain to give evidence of satisfactory workmanship and material quality, and to establish the maximum undetected flaw size.

Ultimate Pressure - The pressure which a pressurized component must sustain without rupture in the expected operating environment.

Proof Factor - A factor which defines proof pressure when multiplied by limit pressure at the design temperature.

Ultimate Factor - A factor which defines ultimate pressure when multiplied by limit pressure at the design temperature.

Criteria:

Proof Factor - A minimum proof factor of 1.2 shall be used unless a greater Proof Factor is determined through fracture mechanics analysis.

Ultimate Factor - A factor of 1.5 shall be used.

Pressurized components shall be proof pressure tested to proof pressure test requirements established by TBD.

4.7.1.3 Fatigue Criteria. A detailed design life cycle history curve shall be developed in sufficient detail that a cumulative damage assessment can be analytically verified for each major component (turbopump, combustion chamber, etc.). In general, this data can be shown by a component load history profile showing usage cycles, load intensities, and environments. The structures and components shall be designed for a fatigue life of four times the number of service life operational cycles. Component level testing to demonstrate fatigue life shall be based on two times the service life operational cycles unless modified by the applicable component design verification specification. Expected minimum (properties based on adequate test data) high cycle fatigue design curves when divided by a factor of four on-cycles shall lower bound all test data. Predicted minimum (properties based on limited test data) high cycle fatigue design curves shall be utilized in conjunction with a factor of ten on-cycles.

4.7.1.4 Protective Treatment. All parts shall be suitably protected from aggressive environments where exposure to the environment may be expected to be detrimental to the engine or its components. Protective finishes shall be selected in accordance with MSFC-SPEC-250, except that protective finishes for electrical connectors shall be selected in accordance with TBD.

4.7.1.5 Compatibility. All material used shall be selected on the basis of having maximum compatibility with the environment with which it is used, with primary importance placed on material - propellant compatibility and the use of nonflammable materials wherever possible.

4.7.1.6 Oxidizer Compatibility. Any material used internally in the oxidizer system of the engine shall be oxidizer compatible as determined by the test procedures of MSFC-SPEC-106.

4.7.1.7 Flammability. All materials used in the engine shall meet the flammability requirements of MSFC-SPEC-101.

4.7.2 Flexible Duct Design Criteria. All flexible metal ducts of two inch inside diameter or less shall be multiple ply construction. The average velocity of the fluid at any station in the flexible duct shall be less than that corresponding to 0.3 mach number. The design of flexible metal ducts shall be such that the mechanical resonant frequency of the bellows system in its operating environment is not coincident with vortex shedding frequency range. All flexible lines and bellows shall be analyzed and designed to exclude or minimize flow-induced vibrations in accordance with 20M02540.

4.7.3 Maintainability. The engine shall be designed for ease of servicing and maintenance while in either the horizontal or vertical attitude and under environmental conditions encountered in sheltered or enclosed areas at the vehicle recovery and maintenance sites. The engine design shall permit necessary inspections, checkouts, and adjustments of engine components with reasonable accessibility as determined by the using service and shall allow required replacement of short maintenance interval components without disassembly of the engine or removal of major components, parts, or accessories. The requirements of this paragraph shall be imposed on any subcontractor maintaining design control of any engine component.

4.7.4 Physical Interchangeability. All components and subsystems having the same contractor part number shall be interchangeable with respect to installation, except that matched parts or selective fits will be permitted when identified to the Procuring Activity. Individual components shall be configured for installation in only one orientation.

4.7.5 Functional Interchangeability. The engine shall be designed with the objective that all operational control system subsystems be capable of replacement without requiring a recalibration firing of the engine. In addition, all components having the same part number shall be capable of replacement without requiring other hardware changes.

4.7.5.1 Orifice Plates. All orifice plates shall be designed to be noninterchangeable. Design of orifice plates shall allow removal and reinstallation with repeatable orifice performance. Orifice diameter tolerance, edge control, and/or fluid resistance variation limits shall be established for each orifice application.

4.7.6 Electrical Design. TBD

4.7.7 Electrical Bonding and Ground. Electrical bonding of equipment and structure shall be in accordance with MIL-B-5087, except the engine shall be designed for Class L bonding; lightning bonding tests shall be the responsibility of the vehicle contractor. The solenoid valves and pressure actuated valves (PAV) on the pneumatic control assembly (PCA) shall be designed for Class H and Class S bonding, respectively. However, the maximum allowable bonding resistance for solenoid valves and PAVs shall be 1.6 ohms and 8.3 ohms, respectively, as verified by Design Verification Testing. The engine shall incorporate provisions for independent grounding to the thrust structure using a separate electrical path.

4.7.8 Electromagnetic Compatibility Engine. The engine electrical components, except the controller, shall be designed to meet the requirements in accordance with MIL-STD-461 with testing to the requirements of MIL-STD-462. The controller shall be designed to meet the requirements of SL-E-0002 with testing to meet the requirements of MIL-STD-462. The overall engine system shall be designed to meet requirements of MIL-E-6051. Electrical transient suppression shall be provided as required.

4.7.9 Failsafe Design. All electrical critical subsystems shall be fail operational after the first failure to any level within the subsystem, i.e. resisters, diodes, wiring, solder joints, etc., and failsafe after the second failure. Where a failure criteria are not technically practical, a waiver must be approved by the contracting agency.

4.7.10 Controller. The controller shall be designed to provide the following features:

a. The read/write memory shall be electrically alterable and capable of being programmed and verified without removing the controller from the engine. A permanent self-loader subroutine must be in residence in each controller memory to perform the programming.

b. Design margins shall be provided and identified in all circuit error budgets.

c. Piece parts shall be derated to 60 percent of maximum rating at the operating extremes, unless otherwise approved by the Procuring Activity.

d. Electrical surfaces which can be bridged shall not be exposed.

e. The assembly shall be easily inspectable and shall be capable of disassembly to the module level without damage to interconnections or mother boards.

f. For internal connection, the use of "EDGE" connectors is not permitted.

g. Software Development shall meet the requirements of MSFC MA-001-006-2H and NMI 2410.6.

h. Circuits shall not be exposed to extraneous voltage and current spikes which will affect reliability or accuracy.

i. Design shall include features to prevent corona, harmful outgassing, contamination, and corrosion.

j. The design shall provide growth capability to accommodate changes dictated by engine system and/or vehicle requirements. The capability shall include memory, signal conditioning, and power circuits, the spare processor computational duty cycle time and unused memory capacity shall be at least 20 percent at the S/W CDR.

k. The controller shall be designed to withstand a voltage transient (droop) to 95 volts AC rms for up to 1.0 second with a maximum duty cycle of 1.0 percent without switching channels or going into a halt mode. The wave shape for 95 volts rms is TBD.

4.7.11 Flight Acceleration Safety Cutoff System (FASCOS)

4.7.11.1 The FASCOS shall be integral to the controller and shall be designed to monitor the oxidizer and fuel pump vibrations and provide inputs to the controller. FASCOS hardware shall provide self-test capability under control of the DCU.

4.7.11.2 The FASCOS design shall be such that no more than one fuel and/or oxidizer pump measurement shall be lost for any single controller failure.

4.7.12 Engine Leakage. External or internal leakage of engine propellants or fluids shall not occur in such a manner as to impair or endanger proper function of the engine or vehicle. For engine checkout and maintenance purposes the engine shall be designed to allow leak check capability of internal and external seals. Leakage monitoring capability shall be provided during testing of nonflight engines on seals which are considered critical or are representative of a family of joints of similar design and operational environment. It shall be a design objective that all separable connections not exceed an allowable gas leakage of 1×10^{-4} scc/sec of helium at specified leak check pressures. For engine checkout, all separable propellant connections shall not exceed an allowable gas leakage of 7×10^{-2} scc/sec of helium at specified leak check pressures. All separable pneumatic connections shall not exceed an allowable gas leakage of 1.5×10^{-1} scc/sec of helium or nitrogen at specified leak check pressures. Hydraulic separable connections shall not exhibit any visible liquid leakage when tested at specified leak check pressures for a continuous period of five minutes.

4.7.12.1 Internal and External Fluid Leakage. Leakage past internal and external static or dynamic seals shall be minimized, and where feasible, disposed at drains provided for the purpose. During propellant loading and prior to engine start, any leakage emanating from the engine thrust chamber exit, vents, or drains that would reach combustible limits, either as a single leak or total engine leak, shall be diluted with an acceptable purge or routed to the interface fluid panel for safe disposal.

4.7.12.2 Checkout Pressure Criteria. Leak check pressure values shall be commensurate with vehicle checkout capabilities and maintenance practices to be established during the engine and stage development

4.7.13 Subsystem Design Features. The engine system shall be designed to be capable of the most stringent of the requirements for operation, checkout or certification.

4.7.13.1 Component Weight. Weight of all component and subsystems shall be held to a minimum, consistent with the use of high strength to weight ratio materials and within the requirements of reliability goals and structural integrity in the environment specified.

4.7.14 <u>Hypergolic Fluids.</u> TBD

4.7.15 <u>Nozzle Design.</u> TBD

4.7.16 <u>Protective Covers.</u> All protective covers designed to protect engine components and connections during storage, shipment, and/or launch preparations, shall be designed to be readily visible and to preclude flange or connector mating until the cover is removed.

4.7.17 <u>Low Pressure Turbopump Mount Design.</u> TBD

4.7.18 <u>Structural Criteria for Pressure Checkout.</u> Pressurized systems for high pressure vessels must conform to the following safety factors during systems checkouts if personnel are present during pressurization"

Proof Pressure = 1.50 X checkout pressure

Ultimate Pressure = 2.0 X checkout pressure